AD NUMBER
AD889588
NEW LIMITATION CHANGE
TO Approved for public release, distribution unlimited
FROM Distribution authorized to U.S. Gov't. agencies only; Test and Evaluation; SEP 1971. Other requests shall be referred to Army Materiel Command, Attn: AMCRD-TV, Washington, DC 20315.
AUTHORITY
USAMC ltr, 14 Jan 1972

AMC PAMPHLET **AMCP 706-120**

AD 889588

ENGINEERING DESIGN HANDBOOK

CRITERIA FOR ENVIRONMENTAL CONTROL OF MOBILE SYSTEMS

Distri[illegible] agencies only;
Test [illegible] 8 DEC 1971. [illegible]ther requests
for this [illegible] to

HEADQUARTERS, U.S. ARMY MATERIEL COMMAND **SEPTEMBER 1971**

attn: AMCRD-TV
Wash DC 20315

AMCP 706-120 ENGINEERING DESIGN HANDBOOK - CRITERIA FOR ENVIRONMENTAL CONTROL OF MOBILE SYSTEMS SEPTEMBER 1971

HEADQUARTERS
UNITED STATES ARMY MATERIEL COMMAND
WASHINGTON, D.C. 20315

AMC PAMPHLET
NO. 706–120

16 September 1971

ENGINEERING DESIGN HANDBOOK
CRITERIA FOR ENVIRONMENTAL CONTROL OF MOBILE SYSTEMS

TABLE OF CONTENTS (Con't.)

TABLE OF CONTENTS (Con't.)

CHAPTER 8. CRITERIA FOR SELECTION OF ENVIRONMENTAL CONTROL UNITS

CHAPTER 9. INSTALLATION GUIDES

TABLE OF CONTENTS (Con't.)

TABLE OF CONTENTS (Con't.)

TABLE OF CONTENTS (Con't.)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Con't.)

LIST OF ILLUSTRATIONS (Con't.)

LIST OF ILLUSTRATIONS (Con't.)

LIST OF TABLES

PREFACE

The Engineering Design Handbook Series of the Army Materiel Command is a coordinated series of handbooks containing basic information and fundamental data useful in the design and development of Army materiel and systems. The handbooks are authoritative reference books of practical information and quantitative facts helpful in the design and development of Army materiel so that it will meet the tactical and the technical needs of the Armed Forces.

The purpose of this handbook is to help fill the need for comprehensive technical documents for regulating the environmental control of mobile systems, such as shelters, vans, and trailers. As used in this handbook, environmental control refers to the regulation of the temperature, cleanliness, and purity of the air in the controlled space. It also includes regulation of the noise and vibration generated by the environmental control equipment.

Following an introductory chapter covering the different aspects of environmental control and a chapter on types of installations, most of the first half of the handbook consists of chapters which describe the military air conditioners and heaters, and the criteria for selecting them. A major chapter offers guides on the installation of environmental control systems. Other chapters discuss methods of minimizing heating and cooling loads and the cooling of electronic equipment, which represent the major demand for environmental control in mobile systems. A final chapter considers collective protection equipment for chemical and biological contaminants.

Various design data and sample design calculations are included in appendixes.

The Handbooks are readily available to all elements of AMC, including personnel and contractors having a need and/or requirement. The Army Materiel Command policy is to release these Engineering Design Handbooks to other DOD activities and their contractors and to other Government agencies in accordance with current Army Regulation 70-31, dated 9 September 1966. Procedures for acquiring these Handbooks follow:

a. Activities within AMC and other DOD agencies order direct on an official form from:

Commanding Officer
Letterkenny Army Depot
ATTN: AMXLE-ATD
Chambersburg, Pennsylvania 17201

b. Contractors who have Department of Defense contracts should submit their requests through their contracting officer with proper justification to the address listed in par. a.

c. Government agencies other than DOD having need for the Handbooks may submit their request directly to the address listed in par. a or to

Commanding General
U.S. Army Materiel Command
ATTN: AMCAM-ABS
Washington, D.C. 20315

d. Industries not having Government contracts (this includes colleges and universities) must forward their requests to

Commanding General
U.S. Army Materiel Command
ATTN: AMCRD-TV
Washington, D.C. 20315

e. All foreign requests must be submitted through the Washington, D.C. Embassy to:

Assistant Chief of Staff for Intelligence
ATTN: Foreign Liaison Office
Department of the Army
Washington, D.C. 20310

All requests, other than those originating within DOD, must be accompanied by a valid justification.

Comments and suggestions on this handbook are welcome and should be addressed to Army Research Office–Durham, Box CM, Duke Station, Durham, North Carolina 27706.

CHAPTER 1

TYPES OF ENVIRONMENTAL CONTROL REQUIREMENTS

1-1 INTRODUCTION

In its broadest sense, environmental control entails regulation of the temperature, pressure, density, cleanliness, and purity of the gas in the controlled space; control of the concentrations of its components, particularly water vapor; the circulation and distribution of the gas; and also the control of noise and vibration. Environmental control also involves provisions for detecting pollutants and warning against their critical accumulations which could cause human incapacitation or death.

The term "air conditioning" covers only the process of treating air so as to control simultaneously its temperature, humidity, and distribution to meet the requirements of the conditioned space.

As used in this handbook, environmental control has two major purposes:

(1) To provide a tolerable habitat wherein degradation of human performance is minimal and also to enhance survival under extreme conditions.

(2) To provide optimum environmental conditions for materials and equipment operation.

These conditions may be incompatible in special cases. For instance, in locations where food is being processed, temperatures near the freezing point are desirable to retard spoilage while a room temperature above 60°F is favorable for personnel. In cases of such mutually conflicting requirements compromises must be sought, however, the compromise must be in favor of the item it was designed to protect—in this case food; personnel can wear protective clothing.

Because of the necessarily high equipment density in many mobile military structures, the space available for personnel may be less than what is considered desirable for operator efficiency. It is, therefore, important to control the environment within the structure to avoid discomfort, fatigue, and other conditions that may cause degradation of human performance.

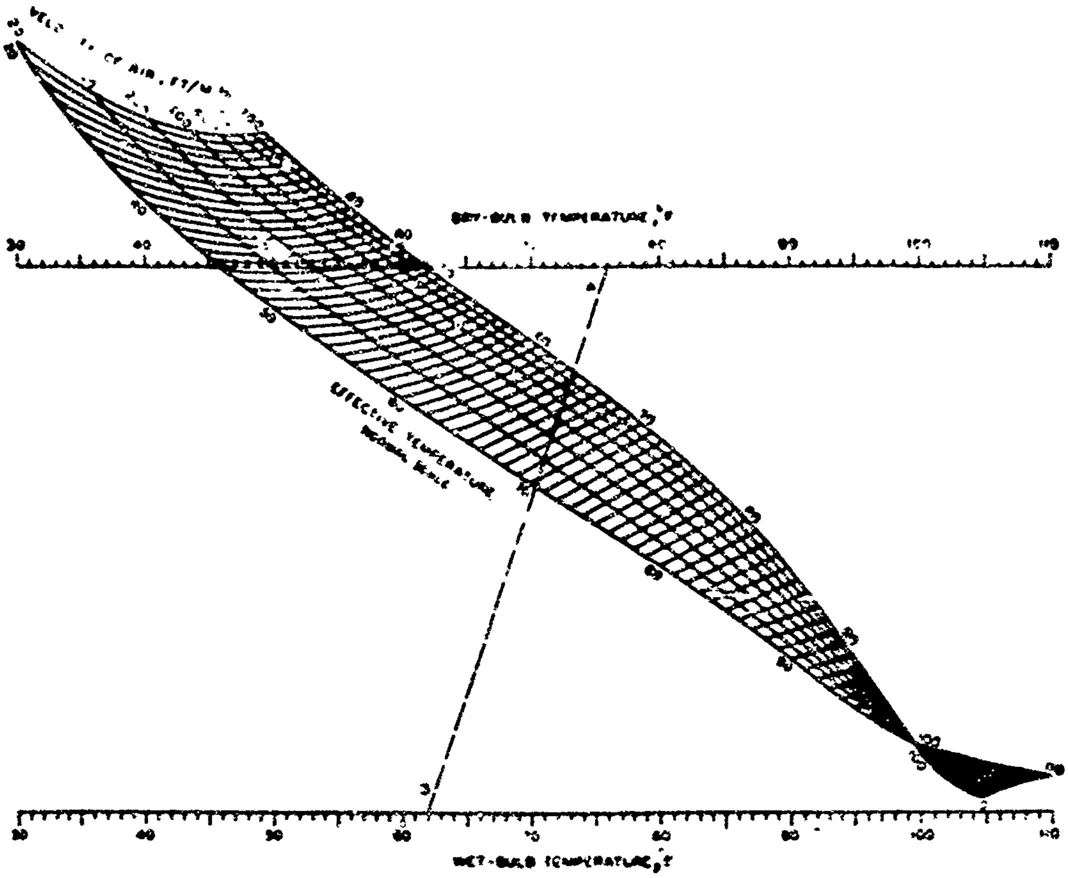
Environmental requirements (temperature, ventilation, noise) for military applications are specified in the standards published by the U.S. Army Human Engineering Laboratories[1*] and also by MIL-STD-1472[2b]. The primary specification is the required Effective Temperature (ET). This parameter, which is defined in the Glossary, combines the effects of temperature, humidity, and air movement on human thermal sensation into a single quantity. In accordance with current military design criteria for environmentally controlled spaces, the recommended ET value is 81.3°F, and the maximum allowable value is 85°F. (The maximum desired dry-bulb temperature is 90°F.)

The effective temperature chart in Fig. 1-1 relates ET to dry-bulb and wet-bulb temperatures and air velocity. Fig. 1-2 illustrates the results of studies at the ASHRAE Laboratory on the effect of environmental conditions on the sensation of comfort.

The major conditions regulated by environmental control are elaborated briefly in the paragraphs which follow. Several design aids, including a description of the psychrometric chart which is commonly used in air-conditioning practice, are given in the appendices of this handbook.

---

*Superscript numbers indicate items in the list of references at the end of each chapter.



HOW TO USE THE CHART Draw line A-B through measured dry-bulb and wet-bulb temperature. Read effective temperature or velocity at desired intersections with line A-B. EXAMPLE Given 67 F db and 62 F wb, read 69 ET at 100 fpm velocity, or 340 fpm required for 66 ET

Figure 1-1. Chart for Determining Effective Temperature for Normally Clothed, Sedentary Individuals. Copyrighted by ASHRAE. Reprinted by permission from ASHRAE Guide and Data Book 1967.

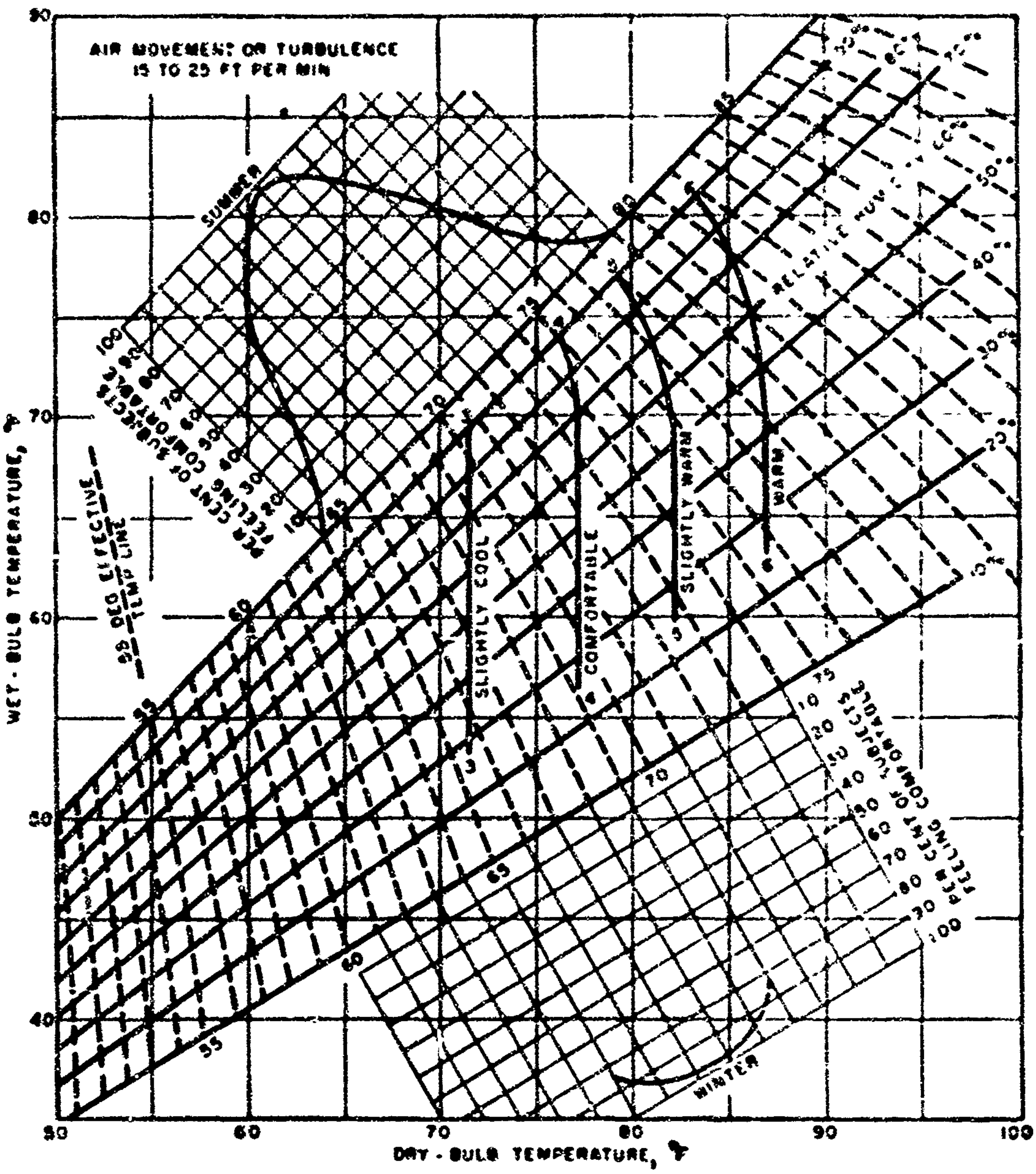
1-2 TEMPERATURE CONTROL

The most common form of environmental control is the regulation of temperature. Usually, a thermostat is used to control the addition or removal of heat as may be required to raise or lower the temperature of the environment

In the type of enclosures considered in this handbook, heat is usually added by the use of electric or combustion heaters, and heat is removed by the use of air conditioners. Most military air conditioners are in the form of environmental control units which include electric heating elements, so that they can be used for heating as well as for cooling purposes. (The specifications of military environmental control units are given in Table 3-1, and those of military heaters are given in Table 5-1.) In addition to the use of electric combustion heaters, heating is sometimes achieved by circulation of a fluid connected to a thermal reservoir as, for example, in the circulation of engine coolant through heaters used in personnel compartments of some military vehicles. Limited temperature control can also be achieved by ventilation with outside air, this is feasible when the temperature of the outside air is low enough so that the required temperature in the enclosure can be obtained with a tolerable rate of ventilation.

1-3 HUMIDITY CONTROL

Humidity control is important because of its effects on both personnel and material. High humidity reduces the comfort of people and causes many materials to corrode and



(The comfort distribution curves show that the maximum percentage of people should be comfortable at 71 ET in summer and at 68 ET in winter. These distribution curves are based on the response of persons immediately after entering a conditioned space. The solid lines (Nos. 3, 4, 5, and 6) show the response of subjects after approximately three hour occupancy. It appears from this chart that persons will feel quite warm when exposed to an environment at 85 ET, the maximum allowable in military applications.)

Figure 1-2. Revised ASHRAE Comfort Chart. Copyrighted by ASHRAE. Reprinted by permission from ASHRAE Guide and Data Book 1967.

decompose. Low humidity may cause difficulties in using certain materials, such as paper and fabrics. The increase of static electricity associated with low humidity may even initiate explosions in some environments.

The amount of moisture in an enclosed atmosphere depends on several factors, the moisture content of outside air used for ventilation, the amount of moisture that may be added or removed by the environmental control equipment, moisture that may be added or removed by processes carried out in the enclosure, and on moisture derived from human respiration and perspiration. When air holds the maximum possible amount of moisture in vapor form it is said to be saturated. Relative humidity (RH) refers to the actual moisture content of the air, expressed as a percentage of the maximum amount it can hold at a given temperature and pressure. The dew point is the temperature at which air with a given moisture content becomes saturated, i.e., the temperature at which its RH is 100 percent. Fig. 1-2 should be consulted for the effect of relative humidity on the comfort of personnel.

The controls of temperature and humidity are intimately related because the saturation vapor pressure of water rises with increasing temperature. Therefore, when the temperature of a given atmosphere is increased without the addition of moisture, the relative humidity decreases. The principal means of raising relative humidity are to spray the air with water or to evaporate water into it. Relative humidity can be lowered by chemical means, though this is not an economical method. More commonly, relative humidity is lowered by decreasing the temperature of the air to be dehumidified to the dew point of air having a moisture content such that mixture with room air or, in extreme cases, subsequent heated air brings the processed air to the desired temperature and humidity.

Dehumidification occurs when air is cooled in an air conditioner if the temperature of the humid air falls below the dew point, causing some of the water vapor to condense. When moist air passes over cooling coils, there is sensible cooling of both the (dry) air and the water vapor; and dehumidification occurs when the temperature of the moist air falls below the dew point. Most cooling coils provide simultaneously both sensible cooling and dehumidification. In such a system, the amount of dehumidification which occurs is dependent on the sensible cooling load; and it may not necessarily meet the humidity requirement of the enclosed space. If not enough moisture is removed, the refrigeration system may have to be combined with a sorption system, or, if too much moisture is removed, a humidifying system may have to be added.

Unlike what happens when moist air is cooled, there is no change in moisture content when moist air is heated – though generally the relative humidity is decreased.

Printing operations[4] provide an example of an application in which humidity control is important. Adsorption and desorption of moisture can cause paper stocks to stretch or shrink; and when these occur non-uniformly, the paper may become distorted. The enhanced development of static electricity in an atmosphere of low relative humidity may interfere with printing operation; on the other hand, high relative humidity can prevent proper ink drying. Depending on the type of printing done and the natural environment of the printing plant, separate control of humidity and temperature may be required.

Computer installations are another example of facilities in which humidity control may be important. Lack of adequate moisture in the atmosphere can interfere with the reeling of magnetic tapes in computer machinery.

1-4 VENTILATION

The purpose of ventilation is to renew part of the air in the controlled space to replenish oxygen and to dilute pollutants such as CO_2, obnoxious fumes, and odors.

Ventilation and circulation requirements for military applications are specified by HEL Standards. For communications systems and related equipment, for example, they are given as[13]

"1. Ventilation facilities should provide a minimum supply of 1000 ft^3 of fresh air per person per hour.

"2. Air circulation around the operator should be less than 100 ft per min and velocities less than 65 ft per min are desirable.

"3. Hot or cold forced-air systems should be designed so that the hot or cold air discharge is not directed on personnel."

Where odors and fumes must be diluted, the needed level of ventilation can be considerably higher than is indicated in Item 1.

When the temperature of the circulated outside air must be increased or decreased to meet temperature requirements, ventilation represents an additional load on the environmental control system. In cases where the heat which has to be removed from a space is generated inside the space a certain amount of air cooling can be achieved by ventilation with outside air provided it is not too hot or humid.

Recovery of recirculated air, as by charcoal filtration, can significantly reduce the required outside air ventilation rates, producing substantial cost savings particularly in systems requiring large amounts of outside air. Recovery methods are discussed in Chapter 12 of Ref. 3 and Chapter 65 of Ref. 5. The economic aspect is treated in Chapter 80 of Ref. 4.

1-6 CONTROL OF CONTAMINANTS AND ODORS

Air contaminants are classified by their physical properties as dust, fumes and smoke, mists and fogs, and vapors and gases. Gases produced when weapons are fired which typically contain carbon monoxide, oxides of nitrogen, and ammonia are one source of noxious substances encountered in military operations. Another source is the exhaust products of engines[16]. The maximum allowable concentrations of these gases and other pollutants (vapors, fumes, dusts, etc.) can be obtained from the Threshold Limit Values published by the American Conference of Government Industrial Hygienists. Maximum allowable concentrations of carbon monoxide are given in Table B-1, Appendix B.

The removal of gases, vapors, odors, and fine mists depends very much on their nature and concentration. If the solubility properties permit it, washing or scrubbing is indicated. Other forms of removal are chemical reaction, combustion, and adsorption on an activated solid substrate such as silica gel and activated carbon, or alumina. Provision is usually made for the reconstitution of adsorbent materials, usually by heating. Particulate matter with sizes down to 1 micron in diameter—such as industrial dusts, pollen, and bacteria—can be effectively removed from the air with common air filters. (See Ref. 3, Ch. 11, Fig. 1.) Special high efficiency filters—made of glass, or glass-asbestos, fibers—are necessary for smaller-sized particulates[6]. CBR* air filters used by the military remove 99.97 percent of particulate matter down to 0.3 micron in diameter.

Activated charcoal is effective in adsorbing many organic vapors (and some inorganic gases) present in low concentrations. In addition to removing obnoxious odors, carbon filtering is also effective in removing vapors injurious to health. The latter property can be enhanced by impregnating the carbon with appropriate chemicals for absorbing the undesired vapor.

The mechanics of the removal of radioactive contaminants is essentially identical to the removal of particulates and gases. Additional problems, however, are posed by the accumulation of radioactivity in the filter

*CBR = Chemical-Biological-Radiological

material. If filters are used with electrical or mechanical equipment, the concentration of radioactive dust may create a health hazard and, thereby, require special handling. The frequent filter changes thus made necessary, with the attendant radiation hazard and disposal problem, add additional burdens on the personnel. The accumulation of radioactive material on filters can be alleviated by the use of inertial dust separators, which can eject approximately 92 percent of the particulate matter before the air is passed through a filter.

If filters are used to remove particulate matter, their effect on the overall environmental control system must be evaluated. For example, the pressure drop across filters increases the required fan power; also, it may be necessary to remove some of the moisture added in air scrubbing or washing operations before filtering.

More information on odor sources and their removal can be found in Chapter 12 of Ref. 3, Chapter 65 of Ref. 5, and Chapter 80 of Ref. 4.

1-6 NOISE AND VIBRATIONS

Environmental control also includes effective means of dealing with noise and vibrations. Noise creates discomfort to personnel and may, at excessive levels, impair their activities or even their health. Vibrations affect not only personnel but also equipment, such as optical equipment and delicate mechanical apparatus. Maximum allowable levels of vibrations for equipment are specified by the U.S. Army Human Engineering Laboratories.[1b,1c]. (MIL-STD-810B, Ref. 2a, specifies vibration and acoustical noise tests, among others, for military equipment.) Refs. 7 and 8 may be consulted for guidance in methods of noise control

There are essentially three sources of noise and vibrations

(1) Sources exterior to the controlled area

(2) People and equipment inside the controlled area

(3) The environmental control equipment itself.

The technical literature on air conditioning usually concerns itself only with the last item Here, the chief sources of noise are motors, compressors, and fans. The noise enters into the space to be controlled via transmission through walls and other solid structures, and through the air ducts. Noises from motors are effectively combated by proper anti-vibration mounting. Sound attentuation in ducts results from absorption at the walls, reflection at openings, and reflection at elbows. Lining the walls of the ducts with absorbing material further increases the sound attenuation.

Maximum noise levels specified by the Army Materiel Command for personnel-occupied spaces and maximum noise levels for various grades of speech intelligibility are given in pars. B-3 and B-4, Appendix B.

REFERENCES

1. Standards of U.S. Army Engineering Laboratories, Aberdeen Proving Ground, Md.:

   a. HEL Standard S-1-63B, *Maximum Noise Level for Army Materiel Command Equipment*, June 1965.

   b. HEL Standard S-2-64A, *Human Factors Engineering Design Standard for Vehicle Fighting Compartments*, June 1968.

   c. HEL Standard S-6-66, *Human Factors Engineering Design Standard for Wheeled Vehicles*, Sept. 1966

d. HEL Standard S-6-68, *Human Factors Engineering Design Standard for Communication Systems and Related Equipment*, Dec. 1968.

2. Military Standards

a. MIL-STD-810B, *Environmental Test Methods*, 15 June 1967, Notice 1, 20 Oct. 1969.

b. MIL-STD-1472, *Human Engineering Design Criteria for Military Systems, Equipment, and Facilities*, 9 Feb. 1968.

3. ASHRAE, *Handbook of Fundamentals*, Amer. Soc. of Heating, Refrigerating and Air-Conditioning Engineers, Inc., New York, N.Y., 1967.

4. ASHRAE, *Guide and Data Book, Applications for 1966 and 1967*, Amer. Soc. of Heating, Refrigerating and Air-Conditioning Engineers, Inc., New York, N.Y., 1966.

5. ASHRAE, *Guide and Data Book, Systems and Equipment 1967*, Amer. Soc. of Heating, Refrigerating and Air-Conditioning Engineers, Inc., New York, N.Y., 1967.

6. J. C. Little, *Filters for Clean Room Service*, Heating, Piping and Air Conditioning, Vol. 37, No. [illegible], 142-146, Sept. 1965.

7. L. L. Beranek, *Noise Reduction*, McGraw-Hill Book Co., Inc., New York, N.Y., 1960.

8. C. M. Harris, Ed., *Handbook of Noise Control*, McGraw-Hill Book Co., Inc., New York, N.Y., 1957.

CHAPTER 2

TYPES OF INSTALLATIONS

2-1 INTRODUCTION

Environmental control units may be mounted in a variety of ways, the choice depending on the type of enclosure being controlled, the type of environmental control unit, and the conditions under which the system is operated. The aim is to make efficient use of space; to provide for convenient maintenance and operation; and to meet the service requirements, including limitations on noise and vibration. In this chapter, brief descriptions of the common types of installations are accompanied by figures illustrating them.

2-2 FLOOR

If space is available, floor mounting usually provides the simplest type of installation, especially for the larger units, since it eliminates the need for special supporting structures. It is not recommended for the smaller air conditioning units because, unless modified, the air outlet and controls would not be conveniently located, and the units inherently are more easily wall mounted. For heaters, however, floor mounting is appropriate for the smaller, as well as the larger units. Locating warm air supplies on or near the floor helps to prevent stratification of room air (as does locating cool air supplies near the ceiling). Fig. 2-1 illustrates three floor-mounted installations of a small heater, and Fig. 2-2 illustrates shelf-mounting of a large heater.

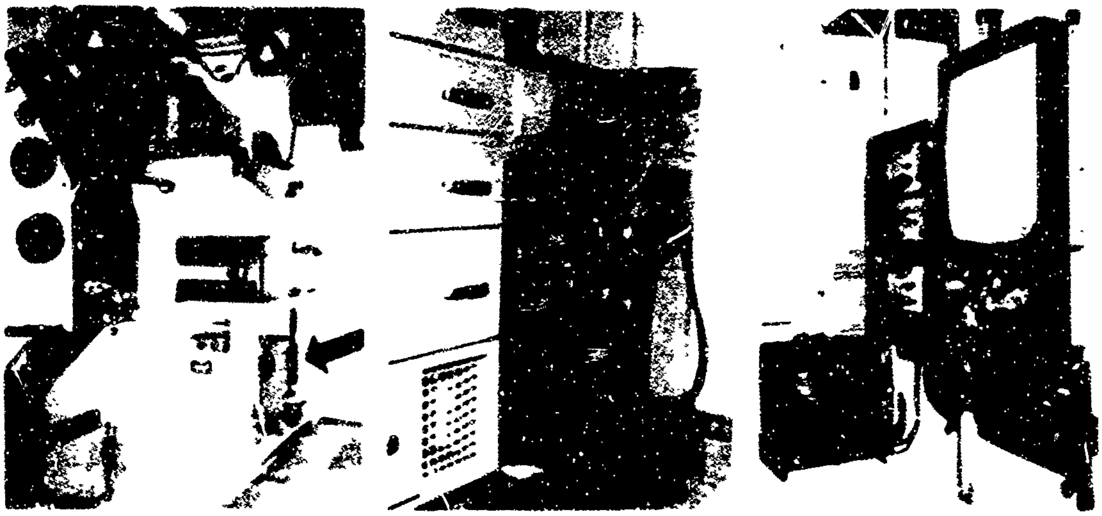
2-3 WALL

Wall mounting, including interior and exterior, is the most common type of mounting. Particularly with smaller units, it permits more efficient use of available space. Provisions for air-conditioner mounting have been made in some van and shelter designs. Suitable frame configurations are used, and ribs are designed to support one or two air conditioners. In some cases, knockout panels are provided to simplify through-the-wall installation.

The simplest wall mounting for single-package air conditioning units is provided when the unit is mounted with the rear of the unit outside the enclosure and the front of the unit inside the enclosure. Some installations, however, may require that the unit be all inside or all outside of the enclosure. In such cases, ducts are needed to accomplish the necessary air flow, and, where cooling is required, the heat of compression must be exhausted to the outside atmosphere. The most common application of wall mounting is at the front end of an enclosure, usually in the upper half of the wall, where there is a minimum of interference with operations inside the enclosure and there is no interference with the cab of the vehicle in the case of truck-mounted shelters. Side wall mounting is not desirable if the unit must protrude through the wall. Fig. 2-3 illustrates a wall mounting on a transportable hut in which the unit protrudes through the wall when in use, but can be withdrawn into a recessed position during transit when the unit is not needed.

2-4 INTERIOR-EXTERIOR

A slight reduction in the required cooling capacity and blower power of air conditioners can be achieved by mounting the condenser section externally and the evaporator section in the wall or, better, inside of the controlled



(A) *Heater installed in portable photographic dark room van (see arrow)*

(B) *Heater installation in mobile ground station construction van (typical installation)*

(C) *Heater installed in shelter showing exhaust protected by perforated grill*

Figure 2-1. Three Floor-mounted Installations of 15,000 Btu/hr Heater

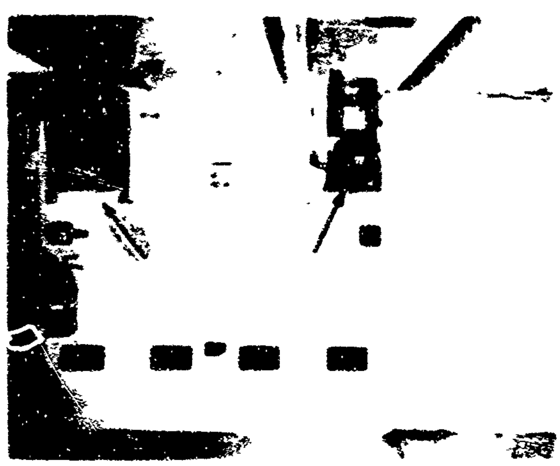
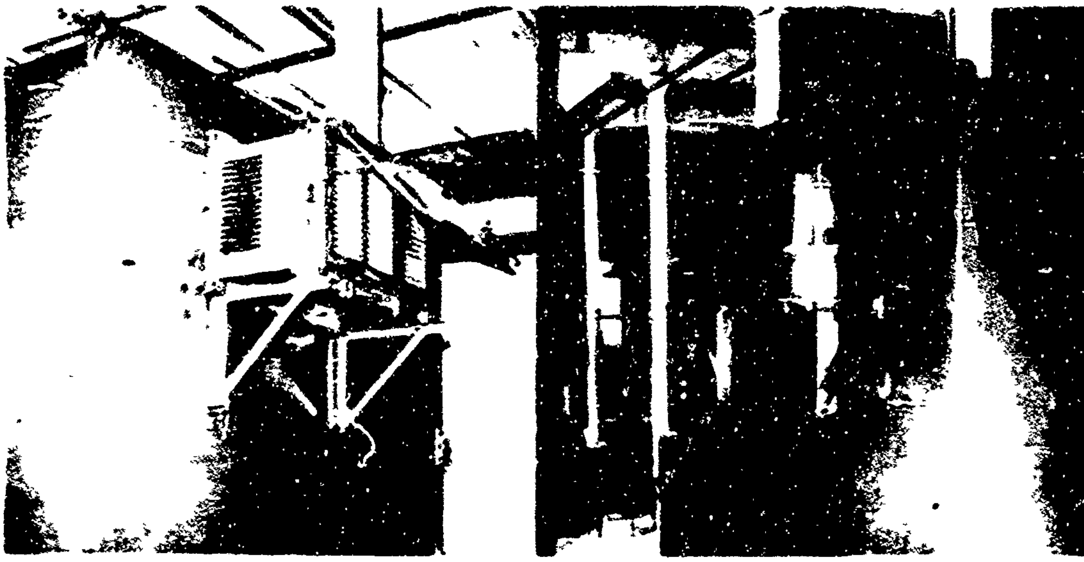


Figure 2-2. Two 60,000 Btu/hr Heaters Mounted Inside Expansible Van



(A) Unit in operating position (B) Unit in transit position

Figure 2-3. 9,000 Btu/hr Air Conditioner Mounted Through Wall of Air Transportable Hut (A special frame allows it to be rolled into recessed position during transit.)

space. However, the prime advantage of interior-exterior mounting is greater installation versatility as described in par. 2-4.2

2-4.1 SINGLE-PACKAGE

Refer to par. 2-3. Fig. 2-4 illustrates this type of installation in the case of a laboratory darkroom van

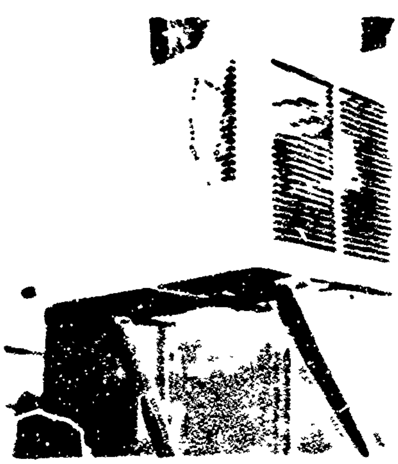


Figure 2-4. 9,000 Btu/hr Air Conditioner Mounted Through Van Wall With Half Inside and Half Outside the Van

2-4.2 MULTI-PACKAGE

Greater installation versatility is provided by environmental control units built with separable sections. Some units have separate condenser and evaporator sections, and one (18,000 Btu/hr) unit is constructed in five sections compressor, condenser, condenser fan, evaporator, and evaporator fan. The sections can be separated and placed in many different configurations, making the unit compatible with a variety of structures. Fig. 2-5 illustrates different types of installation possible with units having separate evaporator and condenser sections. Figs. 2-5 and 2-6 illustrate some of the installations possible with the five-section unit.

A multi-package air conditioner is recommended for structures where large mounting holes would weaken the wall. When the evaporator unit is mounted in the conditioned space and the condenser on the outside, the only wall opening required is a 2- to 3-in. diameter hole for passage of refrigerant and electric lines

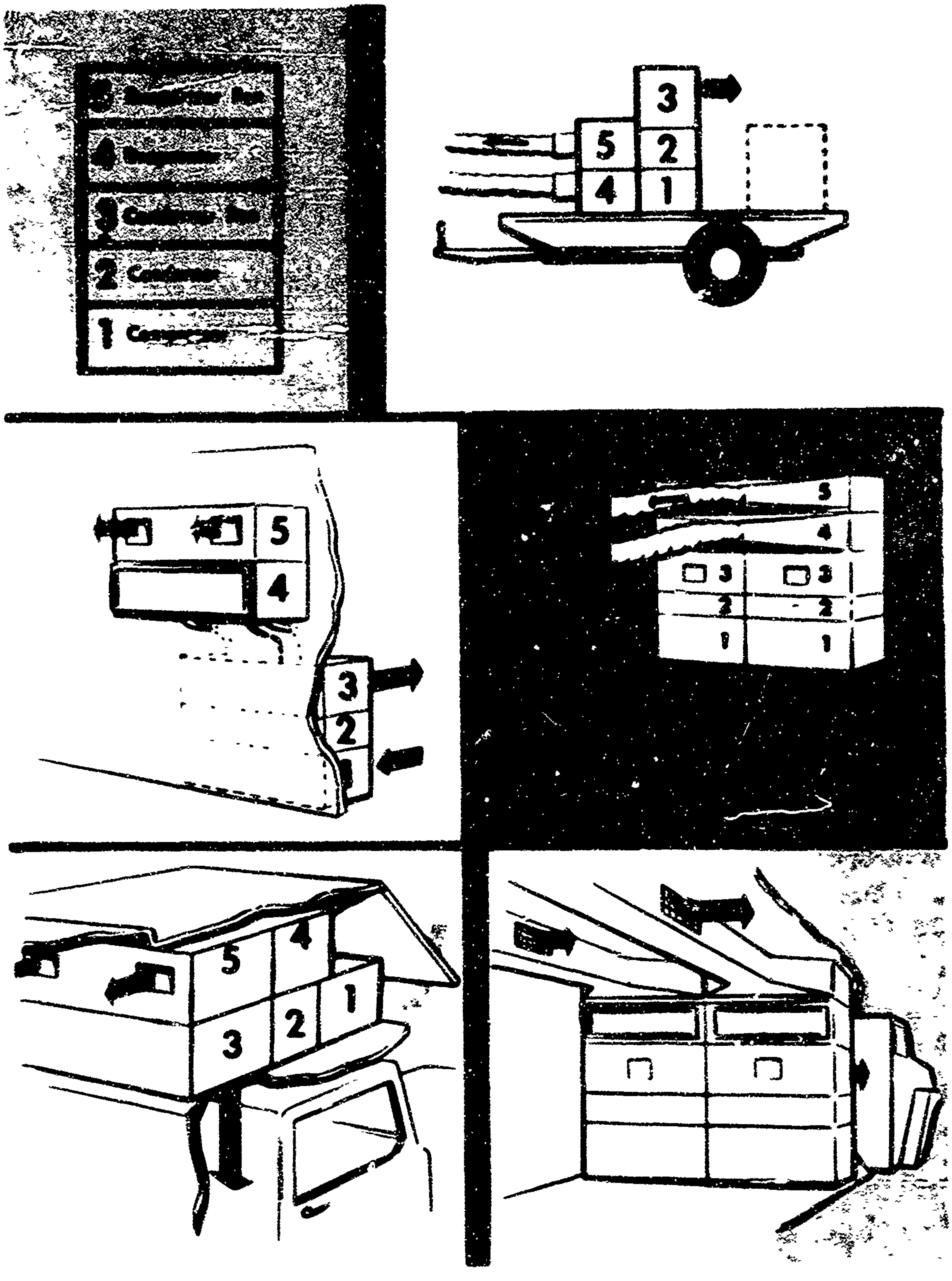


Figure 2-5. Frequently Used Configurations for Mounting 18,000 Btu/hr, Multi-package Air Conditioner

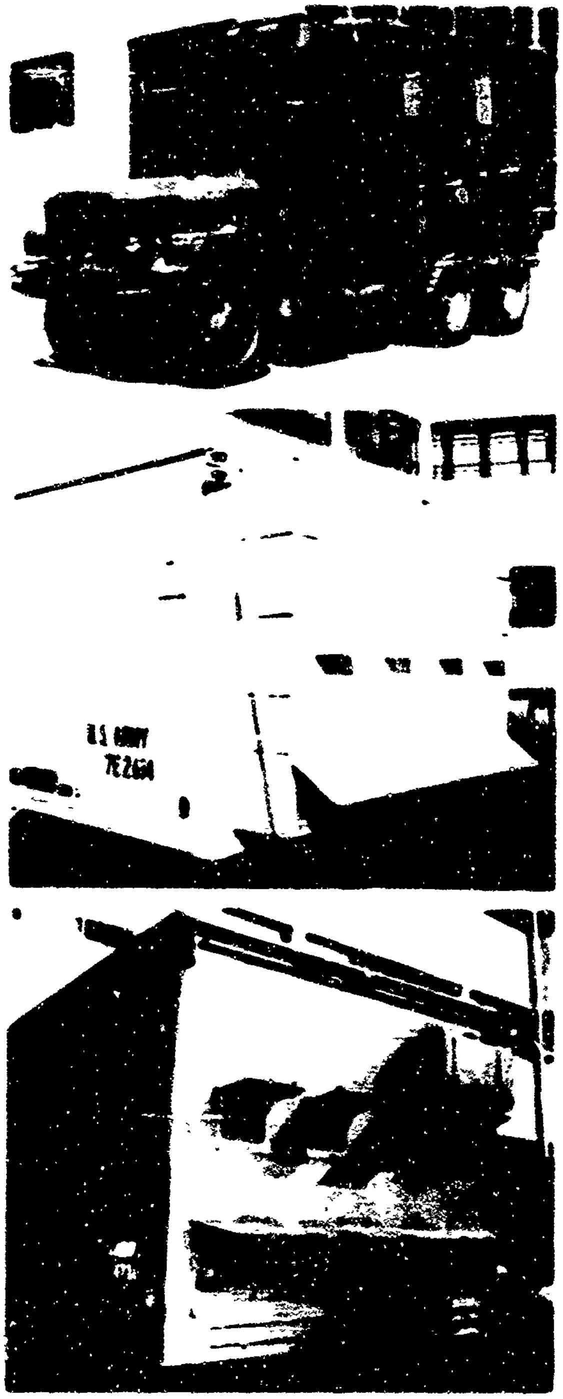


Figure 2-6. Illustrations of Three Mounting Configurations of 18,000 Btu/hr Multi-package Air Conditioner

2-5 MULTIPLE-UNIT

When the heating or cooling load is substantial, and especially if the load is variable, it may be advisable to use two or more units, each carrying a fraction of the load. An advantage of this type of installation is that failure of one unit does not disable the entire system; as long as at least one unit remains operable, the system can meet a portion of the load. A comparable single-unit installation would result in complete shutdown in case of failure. For applications in which a disruption in full service is intolerable, a multiple-unit installation should be used with one or more units as standby in case of failure of an operating unit. Multiple-unit installations may also be applied to systems which encounter large variations in load requirements depending on the season, geographical location, or operating conditions.

Occasionally, special considerations indicate the use of a multiple-unit installation. For example, the conventional 18,000 Btu/hr environmental control unit (Table 3-1), weighs more than two of the conventional 9000 Btu/hr units. Therefore, in this case a two-unit installation would have the advantage of weighing less than a single-unit installation.

To avoid excessive power surges in multiple-unit installations, provision should be made for a time delay between the starting of individual units.

A practical example of a two-unit application to a shelter is given in Ref. 1. The thermostat of one air conditioner was set at the desired temperature level, and the thermostat of the second unit was set about 5°F above the desired temperature. This made one unit operate full time while the second unit cycled on only under extreme conditions, i.e., when the temperature was too high for the first unit to handle the load. With this arrangement there was little danger that both units would start simultaneously, causing a large power drain on the generator. As indicated in a preceding paragraph, unless there is a special arrangement as just described, multi-units would have to be turned on in sequence to prevent an excessive power surge when starting the system.

2-8 REMOTE UNIT

In some applications it may be advantageous or even necessary to mount the environmental control unit remote from the space being controlled. Remote mounting is essential if the structure is not strong enough to support the unit as, for example, in the case of an inflatable shelter. A separately-mounted unit simplifies transportation and speeds installation for field-erected structures. Economies are realized if a separately-mounted unit can service several structures which do not require full-time operation. Remote mounting also makes more space available for other uses within the controlled structure.

Remote environmental control units may be mounted on small trailers or on bases or skids. Type arrangements are shown in Figs. 2-7 and 2-8. Usually, flexible ducts are used for air flow between the environmental control unit and the controlled enclosure. Remote-control panels connected to the unit by cable permit operation to be controlled from within the enclosure. Heat transfer through the walls of the ducts increases the required heating or cooling capacity of the unit, and friction losses through the ducts increase the blower power required for a given flow rate. To minimize both effects, the ducts should be insulated, and they should be kept as short and as straight as possible.

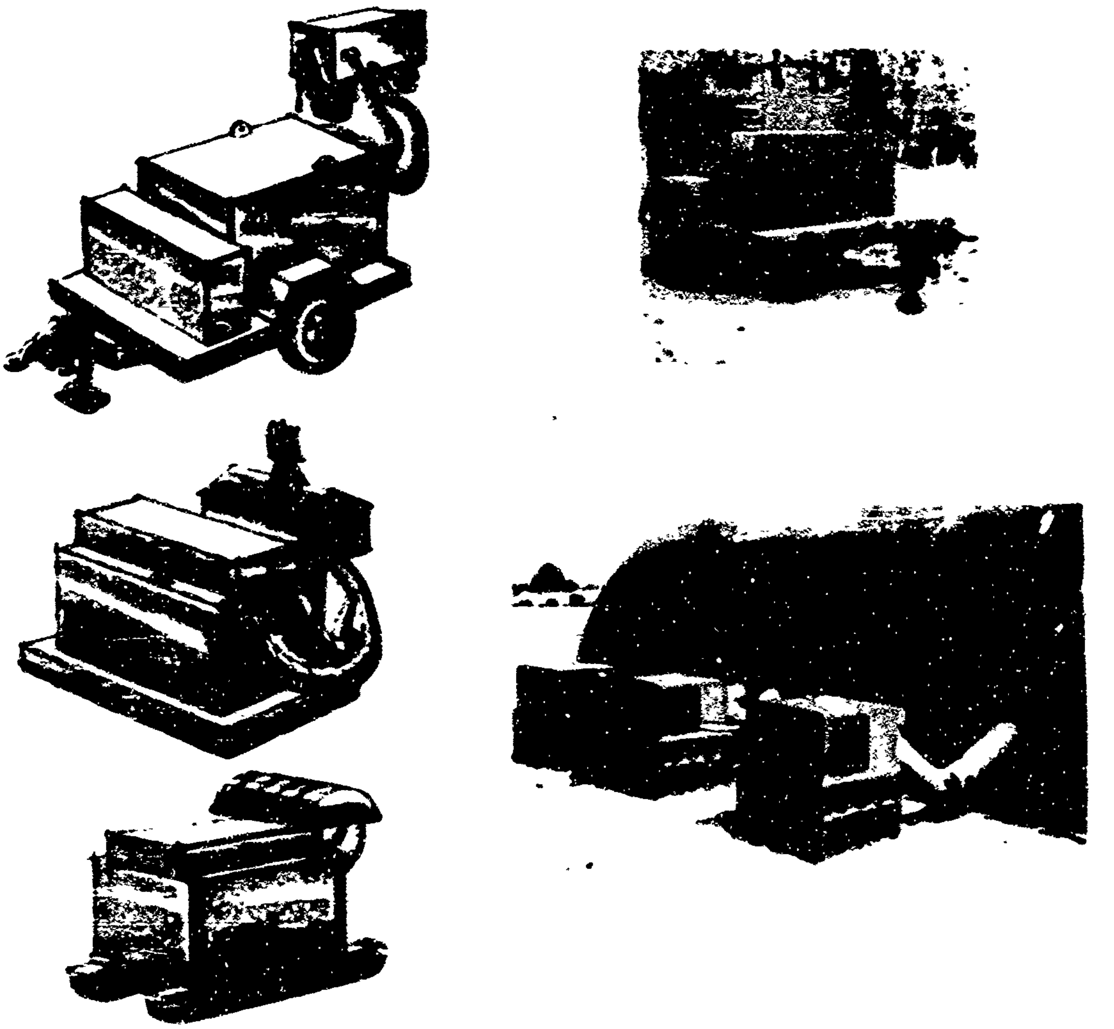


Figure 2-7. Illustration of 9,000 Btu/hr Air Conditioner Mounted Outside an Inflatable Shelter Employing Flexible Ducts for Air Flow

Figure 2-8. View of 60,000 Btu/hr Gasoline-engine-driven Air Conditioner With Duct Storage Compartment

REFERENCE

1. W. M. Emlen, *Reconnaissance Exploitation Test Shelter*, Technical Report No. RADC-TR-66-307, Rome Air Development Center, Griffiss Air Force Base, New York, August 1966 (AD-489 750).

CHAPTER 3

TYPES OF MILITARY AIR CONDITIONERS

3-1 INTRODUCTION

The military air conditioners of interest for applications covered by this handbook have cooling capacities between 6000 and 60,000 Btu/hr. They are listed in Table 3-1 which gives some performance and physical data for military environmental control units*. More detailed information on the configuration of these units can be obtained from Ref. 1 which has drawings of exterior views of the units. The design and testing of some of the compact, horizontal units are discussed in Refs. 2, 3, and 4. It may be noted that all of the *compact* units and many of the *conventional* units are capable of heating – by means of electric heating elements – in addition to cooling. Environmental control units intended for future development, probably after 1970, are listed in Table 3-2.

Wherever possible, the standard units listed in Table 3-1 should be used in designing air-conditioning systems. Units of 6000, 9000, and 18,000 Btu/hr cooling capacity are those used most often. Larger loads are usually met by installing multiples of these smaller units. Special units can be developed for unusual applications only if sufficient lead time is available. Occasionally, it is necessary to use commercial units for these special applications.

In addition to the *Compact Horizontal* and *Compact Vertical* families of environmental control units, which are listed in Table 3-1, Ref. 8 lists the units in Table 3-2 for future development.

*Technical Data and Characteristics bulletins for most of the units, identified by the Federal Stock Number, are available from Headquarters, U.S. Army Mobility Equipment Command, St. Louis, Missouri, or U.S. Army Mobility Equipment Research and Development Center, Fort Belvoir, Virginia.

3-2 SINGLE- AND MULTI-PACKAGE UNITS

Environmental control units are available in both single- and multi-package configurations. As the terms imply, the single-package units are completely self-contained in a single case, and the multi-package units are separable into two or more components which can be mounted in a variety of configurations. The simplest multi-package units are those which have separate evaporator and condenser sections, such as those shown in Fig. 3-1. The two sections are connected by electrical cables and flexible, quick-disconnect, precharged refrigerant lines. A more complex multi-package configuration, shown in Fig. 3-2, has five separable sections – in addition to the condenser and evaporator, the condenser fan, evaporator fan, and compressor are mounted in separable sections. Multi-package units with separable sections are also discussed in par. 2-4.

Single-package units have the advantage of being more compact and lighter than multi-package units of equal capacity and comparable design. As illustrated in Figs. 2-5 and 2-6, multi-package units have the advantage of greater installation versatility. Other advantages of the multi-package configuration include the reduction of inventory investment made possible by the fact that one unit fits many applications and the rapid repair attainable by simple replacement of defective sections.

3-3 CONFIGURATION (HORIZONTAL AND VERTICAL)

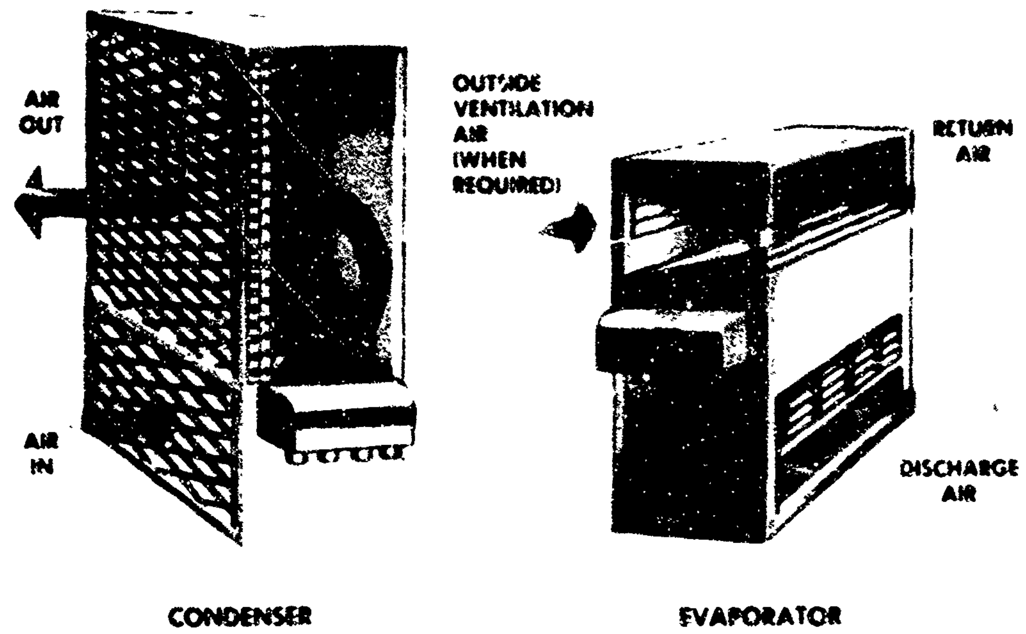
The availability of air conditioners in both

TABLE 3-1

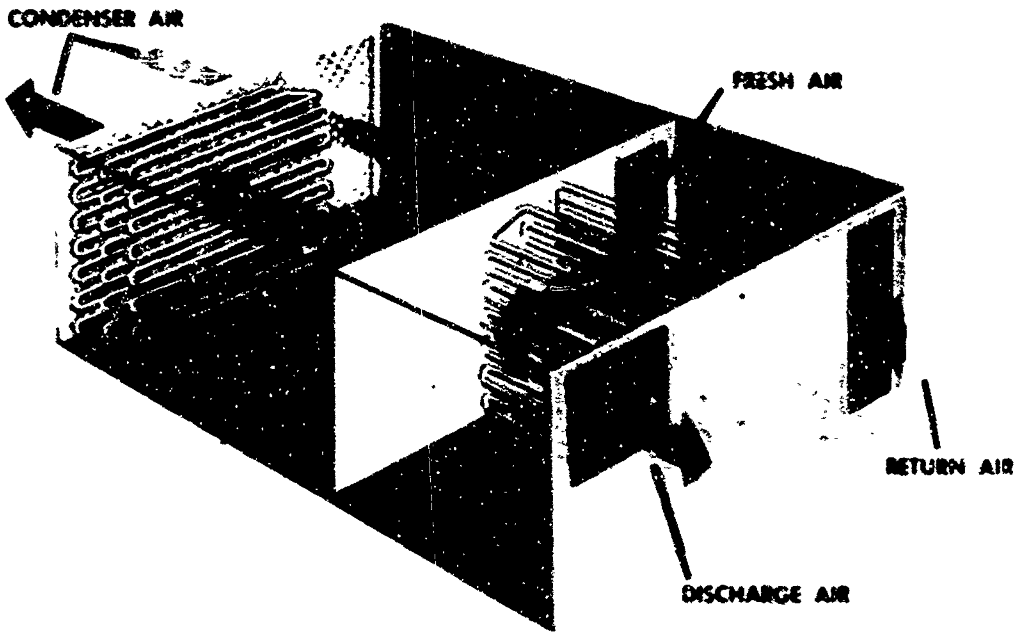
SPECIFICATIONS OF MILITARY ENVIRONMENTAL CONTROL UNITS[b]

Item No.	Cooling Capacity Nominal, Btu/hr	Cooling Capacity Maximum, Btu/hr	Heating Capacity, Btu/hr	Electrical Requirements (Volts/Hz/Phase)	Wires	Maximum Input Power, kW	Overall Dimensions Depth, in.	Overall Dimensions Width, in.	Overall Dimensions Height, in.	Weight, lb	Model Number	Federal Stock Number	Military Specification	Remarks
CONVENTIONAL DESIGN UNITS STD WT														
1	6000	6000	4000	115/ 60/1	2	1.8	Condenser Section 17 6/16	9 1/4	20	130	CE5A 60A	4120 738 7077	MIL A 52424(MO)	[illegible]
							Evaporator Section 17 7/16	9 1/4	18					
2	[illegible]	[illegible]	[illegible]	208/400/3	4	2	Same as Item 1			126	CE6A 400A	4120 738 1048	MIL A 52424(MO)	
3	[illegible]	7700	None	115/ 1/60	3	1.8	26	27	15 7/8	180	None	4120 642 4814	MIL A 14372	
4	[illegible]	17000 (max)	None	115,230/ 60/1		3.2	40	14	(a)	[illegible]	None	4120 [illegible] 1323	MIL A 11216(E)	
5	[illegible]	17000 (max)	None	208,416/400/3		3.6	Same as Item 4			[illegible]	None	4120 [illegible] 3100	MIL A 11216(E)	
6	[illegible]	17000 (max)	None	120,208/ 60/3		3.2	Same as Item 4			[illegible]	None	4120 [illegible] 0074	MIL A 11210(E)	
7	[illegible]	[illegible]	None	208/ 60/3		8.5	41 7/8	[illegible]	37 11/16	530	CE 30HEC60	4120 [illegible] 2640	MIL A 52425(MO)	
8	[illegible]	[illegible] (max)	[illegible]	208/400/3		12	40	24	40	370	None	4120 [illegible]	MIL A 52169(MO)	
9	[illegible]		[illegible]	416/400/3		12	Same as Item 8			370		4120 751 [illegible]		
10	[illegible]	[illegible] (max)	[illegible]	208/400/3		15.0	40	24	40	[illegible]	None	4120 651 [illegible]	MIL A 52327(MU)	
11	[illegible]	[illegible] (max)	None	208,416/ 60/3		11.8	30	33	[illegible] 1/4	1100	CR60C60	4120 720 4321	MIL A 52280A(MO)	
VERTICAL COMPACT UNITS														
12	[illegible]	[illegible]	[illegible]	115/ 60/1		2.1	17	17	35 1/4	180	CE7VAL6-115	4120 [illegible] 1120		
13	[illegible]	[illegible]	[illegible]	208/400/3		2.4	Same as Item 12			180	CE7VAL4-208	4120 [illegible] 1128		
14	[illegible]	[illegible]	[illegible]	115/ 60/1		3.4	17	17	38	180	CE11VAL6-115	4120 [illegible] 1142	MIL A 52513(MO)	
15	[illegible]	[illegible]	[illegible]	230/ 60/1		3.4	Same as Item 14			180	CE11VAL6-230	4120 [illegible] 1140	MIL A 52513(MO)	
16	[illegible]	[illegible]	[illegible]	208/ 60/3		3.4	Same as Item 14			180	CE11VAL6-208	4120 [illegible] 1137	MIL A 52513(MO)	
17	[illegible]	[illegible]	[illegible]	208/400/3		3.6	Same as Item 14			180	CE11VAL4-208	4120 [illegible] 1141	MIL A 52513(MO)	
18	[illegible]	[illegible]	12000	208/ 60/3	6	6.0	17 3/16	20	[illegible] 1/2	200	CE20VAL6-208	4120 [illegible]	MIL A 52364A(MO)	
19	[illegible]	[illegible]	12000	208/400/3	4	6.0	Same as Item 18			200	CE20VAL4-208	4120 [illegible]	MIL A 52364A(MO)	
20	[illegible]	[illegible]	[illegible]	208/ 60/3	4	9.2	[illegible]	21 1/2	[illegible] 1/4	450	CE[illegible]VAL6-208	4120 [illegible] 4136	MIL A 52517(MO)	
21	[illegible]	[illegible]	[illegible]	208/400/3	4	11.9	Same as Item 20			450	CE[illegible]VAL4-208	4120 [illegible] 4137	MIL A 52517(MO)	
22	[illegible]	[illegible]	47000	208/ 60/3	4	15.8	[illegible]	23 7/8	[illegible] 13/16	960	CE[illegible]VAL6-208	4120 [illegible] 1631	MIL A 52516(ME)	
23	[illegible]	[illegible]	47000	208/400/3	4	[illegible]	Same as Item 22			960	CE[illegible]VAL4-208	4120 [illegible] 4138	MIL A 52516(ME)	
HORIZONTAL COMPACT UNITS														
24	[illegible]	[illegible]	7000	115/ 60/1		3.0	23 7/8	25 1/2	16 1/8	200	MCS[illegible]AL6-115	4120 [illegible]		
25	[illegible]	[illegible]	7000	230/ 60/1		3.0	Same as Item 24			200	MCS[illegible]AL6-230	4120 [illegible]		
26	[illegible]	[illegible]	7000	208/ 60/3		3.0	Same as Item 24			200	MCS[illegible]AL6-208	4120 [illegible]		
27	[illegible]	[illegible]	7000	208/400/3		3.1	Same as Item 24			200	MCS[illegible]AL4-208	4120 [illegible]		
28	[illegible]	[illegible]	14200	208/ 60/3		6.5	30	28	20	[illegible]	MC18HAL6-208	4120 [illegible] 1706		
29	[illegible]	[illegible]	14200	230/ 60/1		6.5	Same as Item 28			[illegible]	MC18HAL6-230	4120 [illegible]		
30	[illegible]	[illegible]	14200	208/400/3		6.6	Same as Item 28			[illegible]	MC18HAL4-208	4120 [illegible]		
31	[illegible]	[illegible]	31000	208/ 60/3		12.0	[illegible] 1/16	27 1/8	27 1/8	[illegible]	MC[illegible]HAL6-208	4120 [illegible]		
32	[illegible]	[illegible]	31000	208/400/3		12.0	Same as Item 31			[illegible]	MC[illegible]HAL4-208	4120 [illegible]		
33	[illegible]	[illegible]	47000	208/ 60/3		14.0	44 1/8	41 3/4	27 1/2	[illegible]	MC[illegible]HAL6-208	4120 [illegible]		
34	[illegible]	[illegible]	47000	208/400/3		18.0	Same as Item 33			[illegible]	MC[illegible]HAL4-208	4120 [illegible]		
SPECIAL UNITS														
35	[illegible]	[illegible] to [illegible]	[illegible]	208/400/3		6.35	23 1/8	10 3/4	30	190	[illegible]	4120 [illegible]	MIL A 52380(MO)	Vertical Thin Line
36	[illegible]	[illegible] (max)	None	208/400/3		14.0	48 1/8	[illegible]	[illegible]	[illegible]	CE[illegible]	4120 [illegible]	MIL A 52529(ME)	Trailer Mounted
37	[illegible]	[illegible] to [illegible]	None	Engine Driven			91	44 7/8	[illegible]	[illegible]		4120 [illegible]	MIL A 52528(ME)	Gasoline Engine Driven, Skid or Trailer Mounted

Notes:
a. This unit includes four sections 13 3/4 in. high and one section [illegible] in. high, which can be arranged in various configurations.
b. Data for this table were taken from Ref. MIL Std 3. Since some of the units described are in various stages of development and procurement, it is recommended that USAMERDC, Attn: SMEFB [illegible] be consulted for verification of the above data prior to final selection of a unit.



(A) 60,000 Btu/hr vertical air conditioner



(B) 9,000 Btu/hr horizontal air conditioner

Figure 3-1. Example of Air Conditioner With Separate Condenser and Evaporator Sections (6,000 Btu/hr Multi-package Air Conditioner)

horizontal and vertical configurations facilitates fitting the units to the available space. The horizontal configuration is suited primarily to window and wall mounting, and the vertical configuration is suited primarily to floor mounting. Air flow paths for typical horizontal and vertical single-package units are shown in Fig. 3-3.

TABLE 3-2

FUTURE ENVIRONMENTAL CONTROL UNITS

(1) *Thermoelectric Environmental Control Unit.* 10,000 - 24,000 Btu/hr, 208-V, 3-phase, 60 and 400 Hz

(2) *Waste Heat Powered Environmental Control Unit.* 60,000 Btu/hr

(3) *Mobile Utility Modules.* 18,000; 36,000; 60,000 Btu/hr (Cooling)

These modules will provide cooling, heating, and auxiliary electric power. They will provide also for inclusion of hot water heating and pressurized air equipment when these are specifically required.

(4) *Compact Multiton Air Conditioner.* 10-15 ton (120,000 - 180,000 Btu/hr), 208-V, 3-phase, 60 Hz

3-4 CONTINUOUS AND INTERMITTENT OPERATION

To keep the environmental conditions in the controlled space within the desired limits, operation of the air-conditioning equipment may be controlled by either of two methods. One method involves the intermittent operation of a component, such as a compressor or a fan, so that refrigerant flow or the flow of air across cooling coils, respectively, is turned on or off. The method of modulating control involves varying the rate of flow of refrigerant

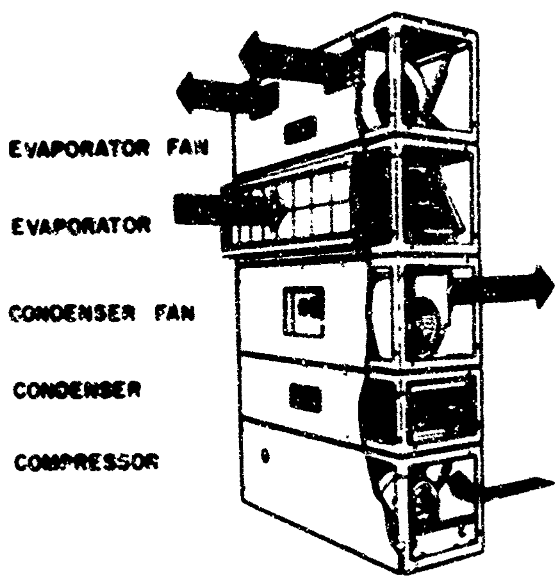


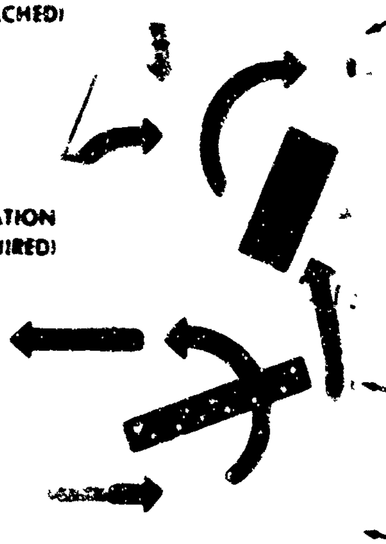
Figure 3-2. 18,000 Btu/hr Multi-package Air Conditioner

or air, while maintaining the equipment in continuous operation. Control systems involving intermittent operation are simpler and cheaper than modulating systems but in many military applications the power surges* that occur when motors are turned on or off cannot be tolerated in other equipment sharing the same power supply. In such cases one must select units provided with modulating control.

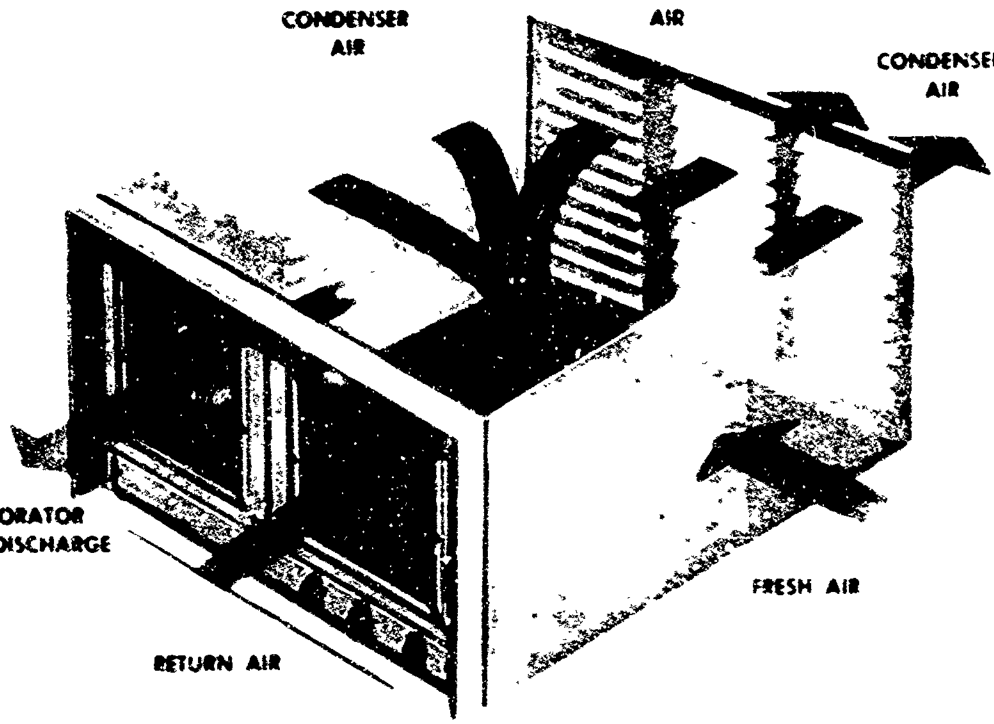
One method of modulating control used in air conditioners is automatic cycling of refrigerant alternately through the evaporator coil and a bypass, depending on whether or not cooling is required. This achieves control of discharge air temperature while allowing the compressor, condenser and evaporator motors to operate continuously. Another method of modulating control is to vary the rate of air flow by means of a variable speed fan or adjustable dampers.

Control systems having continuous fan operation, with intermittent cooling, involve a humidity effect which may not be acceptable in some applications. When the cooling coils are cycled off, the continued fan operation causes re-evaporation of water from the cooling coils and the drain pan, resulting in higher

*Avoiding power surges is also discussed in par. 2-5



(A) 60,000 Btu/hr air conditioner



(B) 9,000 Btu/hr air conditioner

Figure 3-3. Two Examples of Single-package Air Conditioners

humidity in the occupied space. Unless the higher humidity can be tolerated, continuous fan operation should not be used.

3-5 ELECTRIC-POWERED AND GASOLINE-ENGINE-DRIVEN

Most military air conditioners are designed for electrical operation when connected with the power supply indicated in Table 3-1. The military air conditioners are also designed to operate from power supplied by military generators. When system power is limited or the application requires an air conditioner mounted on a trailer or skid mounted, a 60,000 Btu/hr gasoline-engine-driven unit is available.

At the present time, only a special, 60,000-Btu/hr air conditioner is available as a gasoline-engine-driven unit.

3-6 SKID- AND TRAILER-MOUNTED

Air conditioners intended for exterior installation can be mounted on skids or trailers, as illustrated in Fig. 2-8. These portable mountings lend considerable flexibility to installation, and they also facilitate the handling and transportation of the controlled enclosures. The choice between skid and trailer mounting depends on the service required. Skid-mounted units can be placed directly on the ground, but it is preferable to provide a base to prevent trouble due to snow, rain water, and other deleterious conditions on the ground. It is necessary to provide for the loading and unloading of skid-mounted units onto and from the transporting vehicle. Trailer-mounted units may be located wherever room is available, consistent with power and ductwork requirements; and they are easily relocated when necessary. With trailer mounting it is usually possible to provide space on the trailer for auxiliary equipment such as ductwork and collective-protection filter units. Hauling a trailer-mounted unit over long distances, especially over rough roads, might be more cumbersome than hauling a skid-mounted unit in a truck.

REFERENCES

1. Military Standard (Preliminary), *Environmental Control Units, Performance & Installation Data*, U. S. Army Engineer Research and Development Laboratories, Fort Belvoir, Va., Rev. October 1966.

2. *Nominal 18,000-Btu/hr Compact, Horizontal Air-Conditioning Units*, Tech. Information Rep. 33.1.4.2, University of Pittsburgh Research Staff, Wash., D.C., March 1968 (AD-830 057).

3. R. Peterson, *Nominal 36,000-Btu/hr, Compact, Horizontal, Air-Conditioning Units*, Report 1918, Army Mobility Equipment Res. and Dev. Center, Fort Belvoir, Va., Dec. 1967 (AD-665 368).

4. D. P. Swan, *Nominal 60,000-Btu/hr, Compact, Horizontal, Air-Conditioning Units*, Report 1932, U. S. Army Mobility Equipment Res. and Dev. Center, Fort Belvoir, Va., August 1968 (AD-676 119).

5. AMCR 701-6, *Logistics Responsibilities, Assignment of Environmental Control and Refrigeration Equipment*, 4 April 1968.

CHAPTER 4

FEATURES OF MILITARY AIR CONDITIONERS

4-1 INTRODUCTION

The purpose of this chapter is to describe some of the general features relating to the storage, transportation, installation, operation, and maintenance of military air conditioners.

The design objectives of the group of *compact* military air conditioners, which comprises most of the military family, include minimum size and weight, standardization of components, minimum power requirements, and maximum reliability and maintainability. The features of compact conditioners include rugged construction; capabilities for automatically controlled heating as well as cooling; for conditioned air delivery against appreciable back pressure; for ventilation with or without cooling or heating; compatibility with collective protection systems; and self-protection against abnormal temperatures, pressures, and loads; and against cutoff of condenser airflow. The *hot-gas bypass* type of control system is used in the units for precise conditioning without cyclic disturbance of its external electric power supply circuit.

Par. D-1, Appendix D, taken from Ref. 1, specifies the general technical characteristics required of van-type air conditioners designed for military use. A description of the refrigerant circuit with a hot-gas bypass control system is given in Par. D-2, Appendix D.

Although the air-conditioner features are amplified in this chapter, one must refer to other documents for more detailed information. Some pertinent references are:

(1) Ref. 2 lists the family of air conditioners which are to be used in military applications wherever possible, and it gives the procedures which apply when special purpose equipment is necessary. General specifications of the units are listed in Table 3-1; information on the features of military air conditioners can be obtained from the Military Specifications listed there. Additional information, including the discussion of problems and their correction, can be found in development and testing reports and operating manuals, such as Refs. 1 and 3 through 11.

(2) Ref. 12 describes the environmental conditions, including climatic design criteria, that are to be considered in the design, development, and testing of materiel by the Department of the Army. Environmental requirements for materiel of the Mobility Equipment Research and Development Center (MERDC) are clarified in Ref. 13.

(3) Ref. 14 includes specifications of some of the tests used for determining the resistance of equipment to environments peculiar to military operations – such as temperature, humidity, fungus, salt fog, and vibration. Ref. 15 gives the MERDC vibration test procedure for air conditioners.

4-2 SERVICE VERSATILITY

4-2.1 COOLING CAPACITY

The full rated cooling capacity must be delivered at ambient temperatures up to 120°F, with the return air having a dry-bulb temperature of 90°F and a wet-bulb temperature of 75°F. Usually, as shown by the example in Table 4-1, the sensible cooling capacity is specified as a percent of the total

TABLE 4-1

COOLING CAPACITY SPECIFICATION FOR
60,000 BTU/HR VERTICAL, COMPACT AIR CONDITIONER

(From Military Specification MIL-A-52516(MO))

Condition	Ambient Temperature, °F Dry Bulb	Evaporator Air Inlet Temperature, °F Dry Bulb	Evaporator Air Inlet Temperature, °F Wet Bulb	Sensible Cooling Capacity Percent of Total Net Cooling Capacity, %	Total Net Cooling Capacity, Btu/hr
A	120	90	75	60	60 000
C	95	80	67	65	60,000

cooling capacity for different ambient and return conditions.

4-2.2 HEATING CAPABILITY

All of the compact units and some of the conventional units have thermostatically controlled electrical heating capability in addition to the cooling capability. On some units, an electrical interlock prevents operation of the heaters during cooling.

4-2.3 VENTILATION

When cooling or dehumidification are not required, ventilation can be obtained by opening the fresh air inlet damper and operating the evaporator fan alone. When cooling is required, fresh air can be introduced as desired by adjusting the inlet damper

4-2.4 COLLECTIVE PROTECTION COMPATIBILITY

For installations requiring protection against chemical, biological, and radioactive contamination, units are provided with a separate inlet for connection to a collective protector filter unit An auxiliary evaporator air blower may be required to overcome the static pressure loss and ductwork losses inherent to the collective protection system To be compatible with collective protection, air-conditioning units must have the following characteristics

(1) There must be negligible air leakage from the evaporator when under pressure

(2) Use of a blow-through evaporator fan and a pull-through condenser fan is required to help prevent leakage from the outside to the conditioned side If the supply duct from a collective protector is exposed to the outside air, it must be pressurized to avoid recontamination of the supply air

(3) Traps and check valves are required in the condensate drains

(4) Head pressure control is required to permit operation on cooling in low ambient temperature Cooling may be required even with low ambient temperature if the internal heat generation is high enough Accordingly, the head pressure control system is designed to flood part of the condenser and maintain condenser pressure when the ambient temperature drops so low that the pressure differential across the evaporator expansion valve becomes too small to induce the flow of refrigerant needed to satisfy the load

4-2.5 COMPATIBILITY WITH SENSITIVE ELECTRONIC SYSTEMS

Electromagnetic radiation emanating from electromechanical equipment can interfere with the operation of sensitive electronic equipment. Such interference can result, for example, from the current surges generated when motors start and stop. Features which reduce such interference are

(1) Use of a hot gas bypass for temperature control eliminates the stopping and restarting of the compressor after the initial start, thereby preventing current surges. This system is described in Appendix D-2.

(2) Use of a pressure equalizing valve and electrical control of the starting sequence of fan and compressor motors minimizes current surges during the initial, manually-actuated start.

(3) Use of radio-frequency-interference (RFI) control devices such as main power line filter, RFI gasketing, screening, grounding, and shielded cable.*

4-2.6 TOLERANCE OF VARIATIONS IN THE POWER SUPPLY

Air-conditioning units are designed to operate under more than normal variation of the voltage and frequency of the power supply. Typical requirements call for 60 cps units to operate on 50 cps power sources, at rated voltage, and at not less than 70 percent of the rated capacity. Satisfactory operation typically is required with power supplies of rated frequency at voltages between 95 and 110 percent of the rated value.

4-3 EASE OF OPERATION

Military air conditioners are designed for maximum practicable ease of operation. To put most units into operation, it should suffice to connect them to drain lines (condensate lines in the cooling mode) and the proper electrical power source. A simple, readily accessible selector switch should allow the operator to select easily the heating, ventilating, or cooling mode of operation. In the cooling or heating mode, the enclosure temperature should be automatically controlled by an adjustable thermostat. Simple damper adjustment should permit control of the amount of fresh air entering the enclosure.

The use of principles of human engineering in the design of the controls makes them easier to use. Standardization of controls permits personnel familiar with the operation of one unit to operate other units in the same family without additional training.

Safety and ease of operation are enhanced by providing moving parts and parts subject to high operating temperatures with safety guards if they present a hazard to personnel

The elimination of manual functions also contributes to ease of operation. An example is the use of a time-delay circuit to delay start of the compressor, when units are initially turned on, until the fan has run several seconds. This feature also increases reliability by eliminating the possibility of human error in this step of the operation

Ease of operation is also enhanced by design features which make the sound level of air-conditioning units low enough so that there is no interference with satisfactory performance and communication of personnel in the conditioned space. Quiet operation is needed for intelligible conversation at normal voice levels and for satisfactory use of telephone and open microphone-speaker systems. In some cases, external sound attenuators are needed to satisfy the noise requirements.

4-4 MOBILITY

The mobility of military air-conditioners is enhanced by design features which lower the

*When the unit is operated from a remotely located control panel, the interconnecting control cables must be shielded to maintain RFI control. The opening in the front of the unit, resulting from the removal of the panel, must be shielded by a block-off plate

size and weight of the units, by arrangements which yield high resistance to shock and vibration, and by provision of lifting and tie-down devices. Canvas covers can be provided to protect the condenser side of the units during transit. Canvas covers should also be provided for the evaporator sections of skid-mounted units during transit.

The accelerations and vibrations which environmental control units are required to withstand can be found in the Military Specifications referenced in Table 3-1, which also lists the size and weight of the units. Compliance with the specifications insures that the units are capable of withstanding loads associated with transport over rough terrain without requiring *pump-down*† and blocking or tie-down of internal components.

4-5 RELIABILITY AND DURABILITY

The reliability objectives for military air conditioners are

(1) Mission reliability* of 95 percent with a mission time of 24 hr

(2) A mean-time-between-failures* of 1104 hr with 90 percent confidence

(3) A service life of 10 yr, with 4000 hr between overhauls.

Although the mean-time-between-failures is important, it does not suffice to give a total indication of system reliability. Equipment reliability also involves the ease of repair and the simplicity of preventive maintenance procedures. These features are discussed in par. 4-6.

Features now available which contribute to the durability and reliability of military air conditioners include

†"Pump-down" refers to the removal or isolation of the refrigerant.

*Definitions of reliability and mean-time-between-failures are given in par. A-3, Appendix A.

(1) Self protection:

(a) Overtemperature cutoff for heater element

(b) Overpressure cutoff for compressor and overpressure refrigerant release device

(c) Antifrost control for evaporator coil

(d) Automatic cutoff when ambient temperature drops below the design minimum

(e) Overcurrent and winding overheat cutoffs for motors (To avoid needless tripping of circuit breakers used in cutoff circuits, a time delay dependent on the magnitude and duration of the current overload is employed.)

(f) Phase sequence relay for 3-phase units

(2) Construction to withstand salt fog, rain, moisture condensation, fungus, insect attack, dust, sand, and high ambient temperature and humidity

(3) The use of a filter-drier in the refrigerant circuit to remove moisture, filter impurities, and act as an acid neutralizer

(4) Hermetic compressors

(5) Hot gas bypass temperature control

(6) Wiring secured to cabinet and electrical isolators to prevent abrasion of insulation

(7) Use of high temperature soldered joints in the piping to reduce the possibility of leakage in the refrigerant system

(8) Permanent type filters, i.e., ones which can be cleaned by washing or brushing and returned to service

(9) Tube fin coils

(10) Use of an electrical interlock to pre-

vent operation of the heaters when the air conditioner is set for cooling.

4-6 MAINTENANCE

The maintenance requirements for military air conditioners are given in Table 4-2.

Some of the features now available which help to achieve these requirements and which facilitate maintenance when it is required are:

(1) Interchangeability of as many components as possible among the environmental control units in a family should be the rule. This requirement reduces not only the supply costs for spare parts but also the training requirements. Personnel trained to perform maintenance operations on one unit can perform the same function on other units of the same family with little, if any, additional training.

(2) Access panels are provided to facilitate maintenance. Greater facility is achieved if the filter and maintenance access panels are mounted on spring hinges which cause the doors to close when released.

(3) The permanent type air filters, which must be inspected periodically and washed as necessary, are the only items that require frequent attention. The filter cleaning operation require less than 10 min. The out time for routine service is less than 5 percent of the operating time

(4) Motors and compressors are lubricated for life so that no routine lubrication is required.

(5) In some air conditioners, the compressor is mounted on a frame which can be slid out like a drawer to facilitate its removal.

(6) The electrical junction box is arranged to permit removal from the unit to facilitate servicing.

(7) Major electrical components are connected by MIL-STD connectors to facilitate replacement.

(8) Fixed anchor nuts of the floating, self-locking type used to facilitate maintenance and to reduce the number of loose parts.

(9) The number of different types and sizes of fastening devices and similar hardware is kept to a minimum.

(10) Drawings are furnished for each nonstandard military component, including the smallest parts.

(11) A single refrigerant, R-22, is used in all units in the *compact* family.

(12) The refrigerant system includes service valves to facilitate preventive maintenance checking.

(13) A liquid line sight glass indicates whether there is moisture in the refrigerant or a shortage of refrigerant.

(14) Number coding is used in the wiring.

(15) Lifting handles or attachments are provided to facilitate dismounting with safety if trouble shooting is required.

TABLE 4-2

MAINTENANCE TIME OBJECTIVES FOR MILITARY AIR CONDITIONERS

	Operator Crew and Organizational Personnel, hr	Direct Support, hr	General Support, hr
Mean-Time-Between-Maintenance	250	1000	4000
Mean-Time-to-Repair	4	8	24

4-7 INSTALLATION

The following are some of the available features which facilitate the installation of military air conditioners:

(1) Units of each cooling capacity are available in vertical and horizontal configurations to facilitate accommodation to the available space.

(2) A choice of power source type is available.

(3) Mounting is facilitated by lift fittings, tie-downs, and built-in attachment devices. Captive nuts are provided in the base and back of the units.

(4) Provision is made for the attachment of ducts.

(5) Provision is made for remote mounting of the control panel and the thermostat.

(6) The side surfaces of the units are free of air apertures and maintenance access panels to permit side-by-side installation.

4-8 STORAGE

Military environmental control units must meet the requirements of Ref. 12 for static exposure to salt fog, rain, fungus and insect attack, and blowing sand and dust without undue deterioration or excessive cleanup and startup time. Environmental control units must also be capable of storage without damage at ambient temperatures from -65°F to 155°F.

REFERENCES

1. R. B. Sherfy, *Nominal 36,000 Btu/hr, Conventional, Standard Weight, Single-Section, 208-volt, 3-Phase, 60-cycle (Model CE36HBC6-208) Air-Conditioning Unit*, Report 1854, U. S. Army Engineer Research and Development Laboratories, Fort Belvoir, Va., May 1966 (AD-485 823L).

2. AMCR 701-6, *Logistics Responsibilities, Assignment of Environmental Control Units, Including Air Conditioners, Refrigerators, Heaters, Fans, Blowers, and Dehumidifiers*, 19 May 1964.

3. P. E. Chappell, *Nominal 9,000 Btu/hr, Compact, Vertical, 230-volt, Single-Phase, 60-cycle (Model CE11VAL6-230) and 208-volt, 3-Phase, 400-cycle (Model CE11VAL4-208) Air Conditioning Units*, Report 1841, U. S. Army Engineer Research and Development Laboratories, Fort Belvoir, Va., December 1965 (AD-631 325).

4. R. L. Little, *Air Conditioners, 9,000 Btu/hr, Multi-Package, 115-volt 60-cycle and 208-416-volt 400-cycle 4-wire*, Technical Report 1695-TR, U. S. Army Engineer Research and Development Laboratories, Fort Belvoir, Va., 11 September 1961, (AD-272 179).

5. H. R. Lopez, *Engineering Report of Two-Section, 36,000 Btu hr Air-Conditioning Unit*, Technical Report 1611-TR, U. S. Army Engineer Research and Development Laboratories, Fort Belvoir, Va., 23 December 1959 (AD-232 903)

6. O. Oldberg, *Engineer Design Test Report of a 9,000 Btu hr Split-Mounting, Conventional-Type Air Conditioner*, Report 1836, U. S. Army Engineer Research and Development Laboratories, Fort Belvoir, Va., November 1965 (AD-627 388)

7. O. Oldberg, *Development of 60,000 Btu hr, Gasoline-Engine-Driven, Multi-package Air Conditioner*, Report 1796,

U. S. Army Engineer Research and Development Laboratories, Fort Belvoir, Va., 28 January 1965 (AD-459 445).

8. J. F. Ryneska, *Final Report of Service Test of 36,000 Btu/hr, 60-cycle, Single Package, Horizontal, Conventional Type Air Conditioner*, U.S. Army Airborne, Electronics and Special Warfare Board, Fort Bragg, North Carolina, 28 Dec. 1964 (AD-487 491L).

9. G.J. Smith, *Nominal 36,000 Btu/hr, Compact, Vertical, 208-volt, 3-Phase, 60-cycle (Model CE40VAL6) and 208-volt, 3 Phase, 400-cycle (Model CE40VAL4) Air-Conditioning Units*, Report 1861, U.S. Army Engineer Research and Development Laboratories, Fort Belvoir, Va., June 1966 (AD-638 611).

10. TM 5-4120-295-15, *Air Conditioner, Floor Mounting, Air-Cooled 60,000 Btu/hr, 208/416 volts 50/60 cycle, 3-Phase, Carrier Air Conditioning Co. Model 76E34104*, 7 November 1966.

11. J.L. McDonald and L.H. Adkins, *Engineering Report of 6,000-Btu/hr Air Conditioning Unit*, Technical Report 1709-TR, U.S. Army Engineer Research and Development Laboratories, Fort Belvoir, Va., 15 March 1962 (AD-283 264).

12. AR 70-38, *Research, Development, Test, and Evaluation of Materiel for Extreme Climatic Conditions*, 5 May 1969.

13. U. S. Army Mobility Equipment Research and Development Center, *Environmental Requirements for Materiel of the Mobility Equipment Center*, Letter of 28 Jan. 1965, Research, Development and Engineering Directorate, Ft. Belvoir, Va.

14. MIL-STD-810B, *Environmental Test Methods*, 15 June 1967; Notice-1, 20 Oct. 1969.

15. *Test Procedure No. 154 Vibration*, U.S. Army Mobility Equipment Research and Development Center, Fort Belvoir, Va., November 1967.

CHAPTER 5

TYPES OF MILITARY HEATERS

5-1 INTRODUCTION

Military heaters consist primarily of electric, combustion, and automotive types. A brief description follows

(1) *Electric Heaters*. Heat is generated by passage of current through a resistive element. Most of the electric heaters used in mobile systems employ a blower to draw air over the hot element and discharge the heated air into the space to be heated.

(2) *Combustion Heaters*. Heat is generated by burning a fuel, which is usually gasoline or a diesel fuel, in heaters designed for mobile systems. A heat exchanger is used to transfer heat to air which is then discharged into the space to be heated. Exhaust gases are vented separately to prevent contamination of the heated air.

(3) *Automotive Heaters*. Most automotive heaters are designed to make use of waste heat from the engine, air being heated by a heat exchanger through which the engine coolant flows. Automotive heaters are designed for use during transit, while most other heaters are not used during transportation of the equipment in which they are mounted. Automotive heaters may be used to supply heat either to a vehicular component or to the crew compartment.

The families of military heaters are listed in Appendix II of Ref. 1, which gives the logistic responsibilities for environmental control units. Technical data and the characteristics of military heaters are given in a proposed Military Standard[2]. A summary of heater specifications in Ref. 2 is listed in Table 5-1.

As with air conditioners, heaters can be installed in a variety of ways, i.e., they can be mounted on the floor as shown in Fig. 2-1, and small units can be mounted on shelf space as shown in Fig. 2-2. Heaters can also be skid-mounted and trailer-mounted.

All heaters require electrical power for their operation, even if only in the control circuitry. In most cases, an external power source is required, but engine-driven units can be completely self-contained, with a generator as an internal component. Several of the military heaters are listed in Table 5-1 All are combustion heaters which require power only for auxiliary purposes such as control and the operation of electric fans and fuel pumps One of the units described in par 5-3 (Fig. 5-2) is of this type.

5-2 ELECTRIC HEATERS

A variety of requirements have handicapped efforts toward standardization of separate electric heaters. Heaters expected to be available in the near future have relatively small heating capacities, and their chief use is in *spot heating* Units of larger capacity are expected to be developed

Although electric heating systems have lower overall economy than combustion heaters, they have several advantages

(1) Electric heating is clean.

(2) The absence of combustion products eliminates the problem of their disposal and avoids the danger due to toxic gases such as carbon monoxide.

TABLE 5-1

SPECIFICATIONS OF MILITARY HEATERS*

Type	Nominal Heating Capacity, Btu/hr	Electrical Requirements: Nominal Voltage, V	Electrical Requirements: Frequency, c/s	Electrical Requirements: Phase	Operating Weight, lb	Max Overall Dimensions: Length, in.	Max Overall Dimensions: Width, in.	Max Overall Dimensions: Height, in.	Federal Stock No.	Specifications	Notes
VEHICULAR COMPARTMENT HEATERS											
Multifuel Burning	20,000	24	DC		19				2540 692 6848	MIL-H-46792	
Multifuel Burning	30,000	24	DC		21	17.25	6.33	10.42	2540 960 3690	MIL-H-46792	
Multifuel Burning	60,000	24	DC		32	24.12	8.03	13.13	2540 854 4449	MIL-H-46792	
Gasoline Burning	20,000	24	DC		20(approx)				2540 278 7584	MIL-H-3199, Type I	
Gasoline Burning	30,000	24	DC		20(approx)				2540 200 1296	MIL-H-3199, Type I	
Gasoline Burning	60,000	24	DC		30(approx)				2540 555 9230	MIL-H-3199, Type I	
Liquid Coolant Operated (Personnel)	20,000	24	DC			15 5/16	9(approx)	8 3/16		MIL-H-3199, Type II	
Liquid Coolant Operated (Personnel)	30,000	24	DC			20	10 5/8	10 11/16		MIL-H-3199, Type II	
ENGINE COOLANT HEATERS											
Multifuel Burning	15,000	24	DC		15					MIL-H-62078	
Multifuel Burning	15,000	24	DC		25	15	7	11		MIL-H-31778	
Multifuel Burning	30,000	24	DC		35	20	7	11		MIL-H-31778	
Multifuel Burning	60,000	24	DC		45	26	9	13		MIL-H-31778	
Electric	2,560	115	60	1	5	13	4	4		W-H-00150(GSA-FSS), Type I	
Electric	3,415	115	60	1	7	14	4	4	2990 554 0480	W-H-00150(GSA-FSS), Type I	
Electric	5,120	115	60	1	8	18	4	4		W-H-00150(GSA-FSS), Type I	
Electric	7,700	230	60	1	9	20	4	4	2990 554 0479	W-H-00150(GSA-FSS), Type I	
Electric	13,660	230	60	1	11	20	5	5		W-H-00150(GSA-FSS), Type I	
SPACE HEATERS											
Multifuel with Blower	15,000	120	60	1	40	13	12	12	4520 649 8915	MIL-H-52204	a
Multifuel with Blower	Not yet Assigned	120	400	1	40	13	12	12	4520 649 7572	MIL-H-52204	a
Multifuel with Blower	Not yet Assigned	24	DC		40	13	12	12	4520 649 7571	MIL-H-52204	a
Multifuel with Blower	60,000	120	60	1	130	23 3/8	11 1/16	21 3/16	4520 202 6791(M-MU)	MIL-H-11511	a
Multifuel with Blower	60,000	208	400	3		28 3/8	11 1/16	21 3/16		MIL-H-11511	a, b
Multifuel with Blower	60,000	24	DC			28 3/8	11 1/16	21 3/16		MIL-H-11511	b
Gasoline Engine Driven	150,000				300	36	24 1/2	25 1/2	4520 799 0666	MIL-H-52230, Class I	c, e
Electric	5,122 (1.5 kW)	115	60	1	25	12	12 1/2	12	4520 912 3502	Note e	
Electric	17,080 (5 kW)	208	60/400	3	35	13	12	12			f
Electric	34,150 (10 kW)	208	60/400	3	90	11	24	16			f
Electric	68,310 (20 kW)	208	60/400	3	130	11	24	24			f

*General Notes

Data in this table were taken from MIL-STD-5.

Heaters having capacities of 250,000 Btu/hr, or more, were omitted because they are not applicable to the type of mobile systems considered in this handbook.

Heaters to be developed were also omitted if they will replace any of the available heaters listed in the above table, as indicated by the referenced notes.

Referenced Notes

a. These heaters will be replaced with units of full military design type with no important proprietary components.
b. Type classification of these units is not presently contemplated because of lack of requirements.
c. May be used to support air-inflated shelters.
d. This heater will be replaced with one of 125,000 Btu/hr capacity which will be a full military design type with no important proprietary components.
e. Procured by ECOM DA-SC-A-539644.
f. To be developed.

(3) With electric heating there is no fuel-spillage problem, thus there is less danger of causing a fire than there is with combustion heating.

(4) An electric heater is much more simple in construction and control; therefore, more reliable and durable than an equivalent combustion heater.

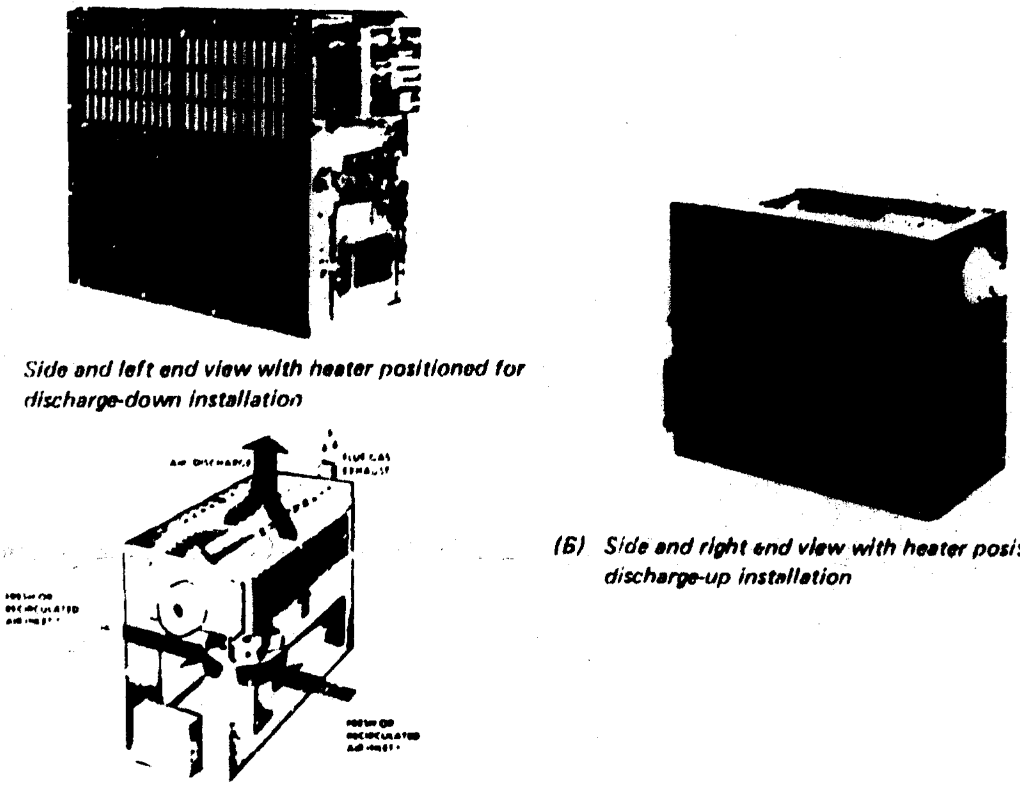
(5) Use of electric heating reduces the possibility of an occupied compartment being contaminated during a CBR attack.

5-3 COMBUSTION HEATERS

As shown in Table 5-1, several combustion heaters are available with capacities between 15,000 and 60,000 Btu/hr; and one gasoline-engine-driven unit has a capacity of 150,000 Btu/hr. Although electric heaters of capacities up to 68,000 Btu/hr are to be developed, the maximum capacity available in existing electric models is 13,660 Btu/hr. Therefore, at present it is easier to meet high-capacity requirements by the use of combustion heaters. Another advantage of combustion heaters using liquid fuels is their capability of providing quick warm-up. The blower-type heaters are the ones best adapted for use in mobile structures such as vans, trailers, and shelters. The nonblower type, in which heat is transferred by radiation and free convection, is better adapted for use in permanent structures.

To further illustrate the features of combustion heaters, two units are described in the paragraphs which follow.

Fig. 5-1 shows a 60,000 Btu/hr compact heater designed primarily for use in mobile



(A) Side and left end view with heater positioned for discharge-down installation

(B) Side and right end view with heater positioned for discharge-up installation

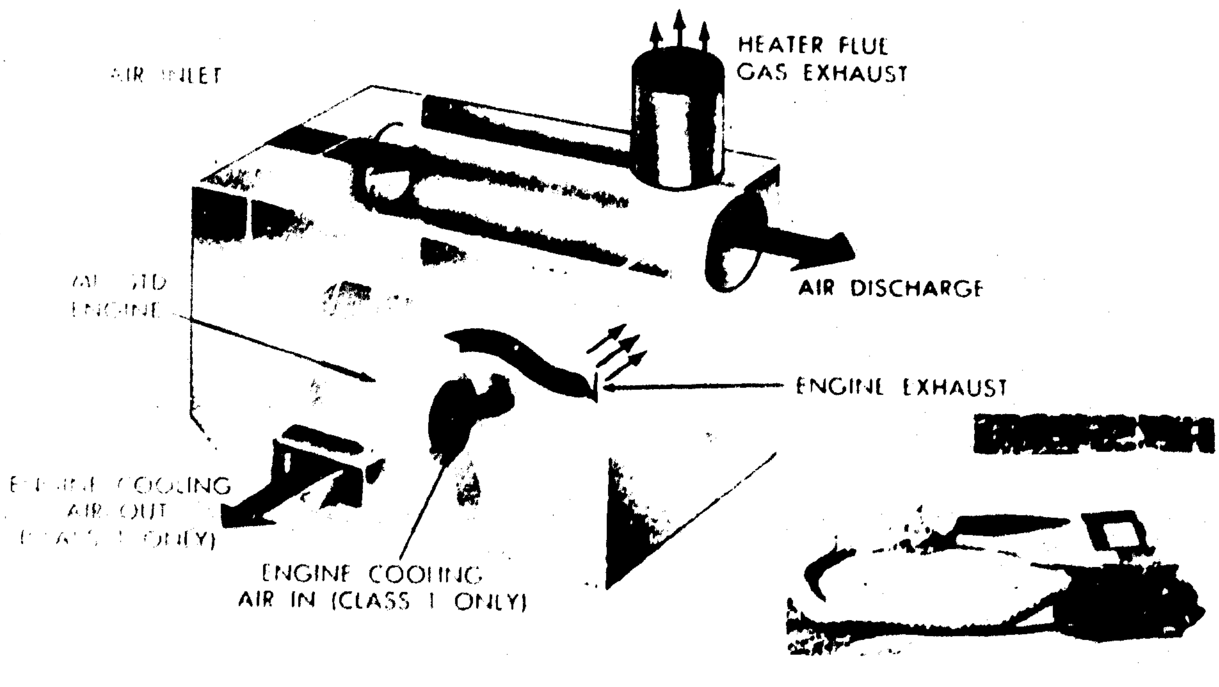
(C) Configuration of heater

**Can be either or both, depending upon installation and position of control switch and damper.*

Figure 5-1. 60,000 Btu/hr Gasoline-burning Heater

structures, although not during transit. It is a gasoline-burning, forced-hot-air type of unit. The damper arrangement permits variation of the ratio of recirculated air to fresh air. The unit may be used as a ventilator when heating is not required. By relocation of several air-handling components, the unit may be arranged for air discharge from the bottom, top, or side. Fuel may be fed to the heater from a supply tank either by gravity or a fuel pump.

Fig. 5-2 shows a 150,000 Btu/hr heater designed primarily for use with military shelters. The heater is mounted exterior to the shelter or other equipment to be heated and is connected to it with flexible ducts. As shown in Fig. 5-2(A), it may also be used to support air-inflated shelters. The heater is a gasoline-burning, forced-hot-air type of unit. The air-discharge blower operates continuously, and the combustion cycling is controlled by a thermostat. The heater electrical circuit is powered by a built-in generator. The prime mover may be either a gasoline engine (Class 1) or an electric motor (Class 2). A fuel pump furnishes fuel to the engine (in Class 1 units) and to the heater combustion chamber.



(B) Configuration of Class 1, engine-driven. Class 2 is motor-driven.

(A) Heater inflates and supplies heat to shelter

Figure 5-2. 150,000 Btu/hr Portable Duct-type Heater

REFERENCES

1. AMCR 701-6, *Logistics Responsibilities, Assignment of Environmental Control and Refrigeration Equipment*, 4 April 1968.

2. Proposed Military Standard, *Heaters, Vehicular Compartment; Heaters, Coolant, Engine; Heaters, Space: Technical Data and Characteristics*, U. S. Army Mobility Equipment Command, Fort Belvoir, Va., 19 June 1968.

CHAPTER 6

FEATURES OF MILITARY HEATERS

6-1 INTRODUCTION

Many of the general features of military heaters are similar to those of military air conditioners which are discussed in Chapter 4. To avoid duplication, this chapter concentrates on those features which apply specifically to heaters and does not elaborate on features common to heaters and air conditioners. More detailed information can be obtained from the references listed in the following paragraph.

Ref. 1 sets forth the responsibilities for, and the general overall policies to be followed in the design and development of heaters as well as other environmental control units. This regulation may be implemented in the near future by publication of a proposed Military Standard[2] which will supply data on vehicular compartment heaters, engine coolant heaters, and space heaters in the military family of heaters. The document will include photographs, installation drawings, and data pertinent to application, supply, and maintenance. Ref. 3 specifies procedures for some of the tests used for determining the resistance of equipment to environments peculiar to military operations. Military Specifications (such as Refs. 4 through 7) should be consulted for detailed information on the design, construction, operation, servicing, and testing of individual units.

6-2 SERVICE VERSATILITY

The available features described in the following paragraphs enhance the versatility of military heaters.

(1) *Multifuel Capability*. Some military heaters are designed for use with a variety of fuels instead of a single fuel. These *multifuel* heaters may be operated with any grade of gasoline up to 100 octane or with diesel fuels of classes DF-1, DF-2, or DF-A. The heaters may be designed to be used primarily with one fuel, but multifuel heaters will have the capability of operating with other fuels when the most suitable fuel is not available.

(2) *Operation in Extreme Cold*. All military heaters are capable of starting and operating at ambient temperatures down to -50°F, and many down to -65°F.

(3) *Ventilation*. Blower-type military heaters are capable of providing ventilation with or without heating.

(4) *Collective Protection Compatibility*. Some military heaters can be installed so that fresh air taken in for ventilation passes through a collective protection system. For example, all of the environmental control units in the *compact* family (Table 3-1) are compatible with collective protection systems.

(5) *Compatibility with Electronic Systems on Same Power Supply*. Military heaters are designed so that they will not interfere with the operation of sensitive electronic systems powered by the same power supply. To help assure that there will be relatively little cyclic disturbance of the power supply, blowers are usually designed to run continuously. Also, the electrical systems of military heaters are designed for electromagnetic compatibility. This means that the heaters will neither emit significant electrical disturbances nor be susceptible to the types of disturbances that may be emitted by other equipment in their vicinity. (The electromagnetic interference

suppression of military heaters is governed by MIL-STD-461.)

(6) *Tolerance of Power Supply Variations.* Military heaters are designed to be operable under more than normal variation of the voltage and frequency of the power supply. The specifications for individual units should be consulted for the allowable variations and the accompanying reductions in capacity.

(7) *Outdoor Installation Kits.* Some heaters are designed primarily for exterior, and others primarily for interior, installation; some of the latter may be obtained with kits which permit outdoor installation. Parts contained in such kits should include flexible ducts, duct adapters, exhaust stack, fuel can, flexible fuel hose and can adapters, and power and thermostat cables.

(8) *Orientation for Operations.* Of particular interest is the possibility of operation of the 60,000 Btu/hr heater in an upright, inverted, or on-the-back position after reorientation of various internal components.

6-3 EASE OF OPERATION

Military heaters have a number of features, based on human engineering, which contribute to ease of operation. These include*:

(1) Toggle-switch starting and shutoff

(2) Standardized controls

(3) Automatic regulation when connected with suitable thermostat

(4) Ability to start and operate while vibrating

(5) Low noise level

(6) Use of quick-disconnect, self-sealing fuel hose connections on combustion heaters

(7) Remotable control panels for convenient location

(8) Instruction plates with adequate information to facilitate correction operation

(9) Conveniently operated damper controls.

6-4 MOBILITY

The features which contribute to the mobility of military heaters are similar to those of military air conditioners. Military heaters are constructed to withstand the shock and vibration of rough road travel. Mobility is also enhanced by compactness, low weight, and by provision of lift and tie-down devices. The use of ducts of the compressible, flexible type helps conserve space during transport. Normally, blocking and tie-down of internal components are not necessary, neither during transport nor during normal operation. However, suitable brackets are provided in some engine-driven units which require that the engine be tied down during transit. Some combustion heaters are capable of operating during transit of the installation.

6-5 RELIABILITY AND DURABILITY

6-5.1 OBJECTIVES

The reliability objectives for military heaters are:*

(1) Mission reliability of 88% with a mission time of 250 hr, at a confidence level of 90%**. In some cases the mission may consist of two 125-hr periods separated by 1 hr of scheduled maintenance.

(2) 2000 hr between major overhauls

(3) Availability of 98%.

*Not all military heaters have all of the listed features. For example, features (3), (6), (7) and (9) are not available on the 15,000 Btu/hr heater, and features (3) and (6) are not available on the 60,000 Btu/hr heater.

*Not all of the available heaters meet these objectives.
**Reliability and mission time are defined in par. A-3, Appendix A.

6-5.2 FEATURES CONTRIBUTING TO RELIABILITY AND DURABILITY

Available *safety* and *self-protection* features which help meet the previously stated objectives include

(1) Discharge air overheat cutoff

(2) Ignition failure cutoff

(3) Flame failure cutoff

(4) Automatic combustion chamber purge cycle after manual cutoff

(5) Motor overheat cutoff

(6) Electrical fuses or circuit breakers to protect against electrical overloads

(7) Provision of enclosures or guards for moving parts that might be a hazard to operating or maintenance personnel

(8) Protection against accidental contact with hot surfaces

(9) Enclosure of electrically-energized parts and provision of grounds as required

(10) Heater ducts capable of handling air at higher than normal temperatures

(11) Use of stainless steel in combustion chambers and many other parts

(12) Construction in accordance with Military Specifications governing resistance to salt-fog, rain, moisture condensation, and dust and sand

(13) Use of filters in the fuel lines to aid in removing moisture and other foreign matter from the fuel

6-6 MAINTENANCE

6-6.1 THREE MAINTENANCE CATEGORIES

The tasks included in the three categories of heater maintenance are listed in the paragraphs which follow.

1. *Routine Maintenance*

a. *Combustion Heaters*

(1) Refill fuel tank. (Not necessary for vehicle heaters if fuel is obtained from main tank on vehicle.)

(2) Inspect for accumulated dirt around heater, in air-intake screen, in fuel screen or filter and clean if necessary.

(3) Inspect housing, ducts, fuel lines, and wiring for looseness, breaks, cracks, or other damage.

b. *Engine-coolant-operated Heaters*. No routine maintenance required.

c. *Electric Heater*. Inspect for loose connections, damage to cord or plug, and leaks in housing, connections, or hoses.

2. *Organizational or Direct Support Maintenance*

a. *Combustion Heaters*

(1) Replace igniter, if necessary.

(2) Replace preheat resistor, if necessary.

(3) Adjust or replace flame detector switch, if necessary.

(4) Inspect damper controls and repair, if necessary.

b. *Engine-coolant-operated Heaters*

(1) [illegible] coolant connections to correct [illegible]

(2) Blow [illegible] out of fan and heat-exchanger

(3) Tighten mounting fastenings.

(4) Inspect damper controls and repair, if necessary.

c. *Electric Heaters*

(1) Repair or replace cord or plug, if necessary.

(2) Inspect and clean heat exchanger.

(3) Inspect mounting fastenings, tighten if necessary.

(4) Remove and replace entire heater if necessary.

(5) Inspect damper controls and repair, if necessary.

3 *Direct or General Support Maintenance (Normally Seasonal)*

a. *Combustion Heaters*

(1) Remove heater from installation, disassemble, clean and inspect internal and external parts.

(2) Replace deteriorated parts.

(3) Readjust and recalibrate as necessary.

b. *Engine-coolant-operated Heaters*

(1) Same as Item (1) for combustion heaters.

(2) Replace heat exchanger, fan, motor, or motor brushes, if necessary.

c. *Electric Heaters*

(1) Same as Item (1) for combustion heaters.

(2) Replace heating element, heat exchanger, fan, motor, or switches, if necessary.

(3) Recalibrate or replace thermostat, if necessary.

6-6.2 MAINTENANCE TIME OBJECTIVES

The maintenance time objectives for military heaters are given in Table 6-1.

6-6.3 FEATURES CONTRIBUTING TO EASE OF MAINTENANCE

Features which contribute to ease of maintenance include:

(1) Development of military heater designs with monodetail drawings aiming for maximum interchangeability of parts and minimum requirements for spare part stocks.

(2) Permanent lubrication where lubrication is required.

(3) Number coding of electrical wiring.

(4) Recessed carrying handles to facilitate dismounting when necessary.

(5) Provision of clips for holding spare fuses, conveniently located on the panel that holds the operating fuses.

(6) Use of captive, quick-disconnect fastenings on covers or plates that must be removed for adjustment or repair operations.

(7) Provision of instruction plates integral with the heater, and readily accessible and readable (not subject to obliteration) giving important servicing procedures, and schematic and wiring diagrams.

TABLE 6-1

MAINTENANCE TIME OBJECTIVES FOR MILITARY HEATERS

	Operator Crew hr	Direct Support hr	General Support hr
Mean Time Between Maintenance	125	1000	3000
Mean Time to Repair	2	8	24

(8) Design considerations which minimize assembly of parts in wrong combinations

(9) Design considerations which minimize necessity to hold heavy or awkward parts during assembly

6-7 INSTALLATION

The versatility of heater installation is enhanced by the following features of military heaters:

(1) Deflector hoods or grills to direct the discharge air as required in those installations in which ducts are not used

(2) Long cable on main thermostat permitting best location for control accuracy

(3) Compact control panels that can be located remote from the heater permitting installation where best for operator convenience

(4) Multiposition operability provides capability of conforming to configuration of the available space

(5) Interchangeable return-air and fresh-air inlets

(6) Built-in fasteners or other provisions for mounting

(7) Availability with different electrical requirements, permitting adaptation to all anticipated sources of power

(8) Outdoor installation kits to permit applications where the heater must be placed outside of the heated space

(9) Weather and corrosion resistance to diminish deterioration in exterior installations

6-8 STORAGE

Storage requirements for military heaters are the same as those for military air conditioners. The units must meet the requirements of Ref. 8 for storage without damage at ambient temperatures from -50° to 160°F and for static exposure to sea salt fallout, rain, and blowing sand and dust without undue deterioration or excessive cleanup and startup time.

REFERENCES

1. AMCR 701-6, *Logistics Responsibilities Assignment of Environmental Control and Refrigeration Equipment*, 4 April 1968.
2. Proposed Military Standard, *Heaters Vehicular Compartment, Heaters Coolant Engine, Heaters Space Technical Data and Characteristics*, U. S. Army Mobility Equipment Command, Fort Belvoir, Va., 19 June 1968.
3. MIL-STD-810B, *Environmental Test Methods*, 15 June 1967, Notice-1, 20 Oct 1969.
4. MIL-H-11049C, *Heater Duct Type Portable, Gasoline 250,000 Btu/hr*, U. S. Army Natick Laboratories, Natick, Mass., 27 July 1965, Ammendment-1, 21 March 1966.
5. MIL-H-11511D, *Heater Space Multifuel With Blower 60,000 Btu/hr*, U. S. Army Mobility Equipment Command, Fort Belvoir, Va., 14 Dec. 1967.
6. MIL-H-52204B, *Heaters Space Multifuel With Blower 15,000 Btu/hr*, U. S. Army Mobility Equipment Command, Fort Belvoir, Va., 13 Dec. 1967.
7. MIL-H-52230A, *Heaters Duct Type Portable 15,000 Btu/hr*, U. S. Army Mobility Equipment Command, Fort Belvoir, Va., 12 Dec. 1967.
8. AR 70-38, *Research Development Test and Evaluation of Materiel for Extreme Climatic Conditions*, 5 May 1969.

CHAPTER 7

METHODS OF MINIMIZING COOLING AND HEATING LOADS

7-1 INSULATION

Increasing the insulation of a structure is one way of reducing environmental control loads. By reducing the rate of heat transfer through the enclosing surfaces, both heating and cooling loads are reduced. For maximum effectiveness, insulation must be applied at all exterior boundaries of the structure walls, roof, and floor. An additional benefit of insulation is that it can also function as a noise absorber if properly selected and installed.

A typical shelter wall has a double-walled sandwich configuration consisting of aluminum skins with a plastic foam filler. To reduce thermal conductance where framing members provide a heat path between inner and outer skins, the framing members may be separated from the shelter skin by sections of plywood. The disruption of the thermal path by the plywood sections helps to prevent localized condensation* as well as to lower the overall heat transfer rate. A typical overall coefficient of heat transfer for this type of construction is 0.35 Btu/(hr-ft^2-°F). The value of this coefficient can be kept low by reducing wall discontinuities and openings and by minimizing the number of feed-through connections such as jacks on entry panels, ground lugs, fuel lines, and drain lines.

For use in mobile military equipment insulation must be resistant to shock and vibration, and it must be nonhygroscopic. Although the use of foamed plastic insulating materials with closed cells reduces the moisture absorption in this type of insulation, sealing out vapors remains a major problem.

*In cold weather, the sections of plywood help to keep the temperature of the inner skin above the dew point of the inside air.

7-2 REDUCTION OF SOLAR LOAD

7-2.1 GENERAL

Solar radiation incident on the external surfaces of a structure may have a marked influence on heat transmission through the walls. The total incident radiation is partly reflected, partly absorbed, and partly transmitted. In general

$$\rho + \alpha + \tau = 1, \qquad (7\text{-}1)$$

where ρ is the reflectivity of the surface, α the absorptivity of the material and τ its transmissivity. The values of these quantities depend on the angle of incidence of the radiation, and the type of material and its thickness. For standard olive drab paint the dominant factor is the absorptivity which is approximately 0.92. For clear double-strength glass at normal incidence, the values of the three factors are the following

$$\alpha = 0.05,$$
$$\rho = 0.08,$$
$$\tau = 0.87$$

For a bronze, gray, or green heat-absorbing glass of 1/4-in. thickness the value of τ is reduced to about 0.46.

Ref. 1 gives a good account of the properties of solar radiation, its wavelength distribution, the effect of the earth's atmosphere, the distinction between direct solar radiation and diffuse sky radiation, the daily and seasonal variations of solar radiation, and the relation to geographical location. The methods for estimating the effect of solar radiation on heating and cooling loads are presented in Refs. 1 and 2. A discussion of

solar radiation with particular application to military equipment is given in Ref. 3.

Although the designer of environmental control systems must provide adequate capacity to handle the worst solar loads anticipated, the user of the equipment can sometimes take steps that will reduce the solar load and permit more efficient operation. Unless other restrictions prevent it, the structure itself can be oriented to minimize the solar load. For example, the structure can be oriented so that the solar radiation falls predominantly on a short end wall instead of a wide side wall.

Some of the methods described in the paragraphs which follow, for reducing solar heating loads in the field, may be unnecessary if the environmental control equipment has adequate capacity. However, there are occasions when the cooling capacity may be inadequate or marginal, and a knowledge of emergency methods of reducing solar heating loads can be put to use*. Furthermore, even if the cooling capacity is adequate, it is well to take advantage of convenient methods of reducing the load on the environmental control equipment.

7-2.2 REDUCTION OF WINDOW AREA

Window areas have high heat transfer coefficients compared to the rest of a typical shelter wall. Therefore, it is desirable to minimize window areas, omitting them altogether if possible. However, this is not to deny the fact that properly oriented windows on a bright sunny day may admit enough solar radiation to comfortably heat a room without resorting to heating equipment.

The overall coefficient of heat transmission for an uncoated single glass is approximately 1 Btu/(hr-ft^2-°F) assuming still air on the inner surface and a 7.5-mph wind at the outer surface. This is nearly 3 times the overall heat transfer coefficient for a typical shelter. The rate of heat transfer through window areas can be reduced by double-glazing, but this is seldom practical in transportable equipment. Furthermore, faulty double-glazing, which does not produce a real dead air space, may encourage fogging and the growth of fungi.

Except where special applications may require windows, it is best to eliminate them. Windows do not take the place of artificial lighting which must be provided anyway for night operation. Furthermore, windows would have to be blacked out under combat conditions.

7-2.3 SHADING

The contribution of solar radiation to cooling loads may be reduced substantially by the use of shading devices to exclude the sun's rays.

Windows can be shaded internally with roller shades, curtains, or blinds. Externally windows can be shaded with awnings, overhangs, and other projections. Louvered sun screens are also available for use external to window surfaces; their advantages compared to internal screens are described in Ref. 5. Most of these devices are usually not practical for military use. For shelter use, an external window shutter hinged along the top of the window makes a practical shading device. When supported open, it would act as an awning, and it could be closed during transport. The shutter could also serve as a blackout curtain. Lateral projections are required for shading when the altitude angle of the sun is so small that overhangs and awnings are incapable of shading a window. It is not practicable to shade windows from diffuse sky radiation and radiation from the surroundings.

Shading also may be applied to entire structures. Fig. 7-1 illustrates the use of shading to reduce solar heating of systems. Under no conditions should the movement of air necessary to remove the heat of com-

*Ref. 4 mentions a case in which the first step taken to alleviate overheating of vans was to paint the roofs white. Additional steps taken when warmer weather arrived were to erect tarpaulins above the vans and to direct a continuous spray of water over the vans.

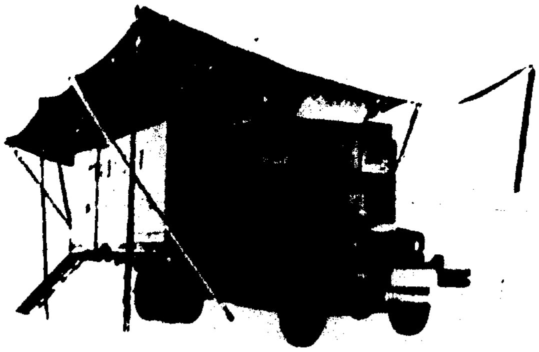


Figure 7-1. Example of the Use of Shading to Reduce Solar Heating of Air Conditioners

pression be interrupted or obstructed. Note that an air space for ventilation must be provided between the item being shaded and the canopy if a significant reduction in heat is to be obtained by shading.

Shading may be achieved through the judicious location and orientation of the structure. For example, the orientation can be chosen so that the walls most susceptible to solar radiation such as windowed walls, walls with environmental control units mounted in them, walls with air intakes, etc.—are on shaded sides. Furthermore, the entire structure can occasionally be shaded by proper location with respect to other structures and natural objects such as trees.

Wall-mounted cooling units for efficient operation should be located to receive a minimum of solar radiation.

7-2.4 INCREASING REFLECTIVITY OF EXTERIOR SURFACES

Most exterior surfaces of military equipment have low reflectivity, and, unfortunately, it is usually not practicable to increase the reflectivity significantly. However, when other restrictions do not rule it out, a reduction in the cooling load due to solar radiation can be obtained by increasing the reflectivity of exterior surfaces.

An indication of the possible improvement can be gaged by noting that the absorptivity for solar radiation of standard olive drab paint exceeds 0.9, while the absorptivity of a glossy white can be as low as 0.2. In arctic regions, where white paint does not interfere with camouflage requirements, its benefit results from the fact that its low emissivity decreases heat losses from the structure.

The U. S. Army Coating and Chemical Laboratory, Aberdeen Proving Ground, Maryland, has developed solar heat reflecting (SHR) coatings* of low visibility, which can be used where the high visibility of white paint is objectionable. Low energy absorption while retaining a dark camouflage color is achieved by having reflectance in the infrared region of the spectrum. These coatings have reflectances of about 65% for infrared radiation in the range 0.7-2.0 microns. SHR paints have been shown to be very effective, having produced temperature reductions of 10° to 20°F when used instead of standard paints. Olive drab has been the color of most of the SHR paints produced, but grays, tans and even near blacks have been developed. An evaluation of solar heat reflecting coatings is given in Ref. 6.

The solar radiation transmitted through window areas can be reduced by a commercially available reflective film†. It consists of a 1-mil thick polyester film with a vapor-coated backing of aluminum, of such transparency (one way, looking out) that visibility remains good.

7-3 INDEPENDENT VENTILATION OF HEAT-RELEASING EQUIPMENT

If heat-releasing equipment can be isolated,

*One SHR paint, the characteristics of which are described by MIL-P-46096, is available in one-gallon cans under Federal Stock Number (FSN) 8010-914-0081. Another paint is described by MIL-P-46117, and a highly reflective undercoat is described by MIL-P-46127.

†"Scotchtint" solar control film, manufactured by the 3M Co., 3M Center, St. Paul, Minnesota

it may be possible to reduce the cooling load by ventilating the equipment independently of the rest of the enclosure being controlled. For example, this can be done with electronic equipment which requires ventilation, but which can tolerate temperatures higher than the maximum temperatures allowable in personnel areas or other parts of the controlled space. Also, there may be circumstances in which the temperature of the outside air is too high for the personnel areas but low enough for ventilation of the electronic equipment. A separate ventilating system could then bring in outside air, pass it through the electronic equipment, and exhaust it to the outside. Since the temperatures in all parts of such an isolated system would be higher than those in the personnel-occupied space, greater effectiveness would be achieved by insulation of the system. It is usually not practicable to apply insulation to electronic equipment cabinets, but components such as ductwork and fan housings can be insulated. Of course any leakage of air used to ventilate the electronic equipment into the personnel space must be avoided. (Appendix D of Ref. 7 describes a system for using outside air to cool instrument racks.)

Separate ventilation of heat-releasing equipment is not practicable if protection against chemical and biological agents is required. Not only is it usually impossible to seal such systems so that outside air could not leak into personnel spaces, but contamination of the equipment itself may be unacceptable.

The technique of isolation can be applied also to other aspects of environmental control such as the control of humidity, dust and odors. Separate ventilation of equipment which excessively generates water vapor, dust or odors may simplify the solution of the overall environmental control problem. For example, separate control of photo-processing equipment, which releases vapors at an excessive rate, reduces the dehumidification load that would be experienced if the vapors were released directly into personnel-occupied spaces.

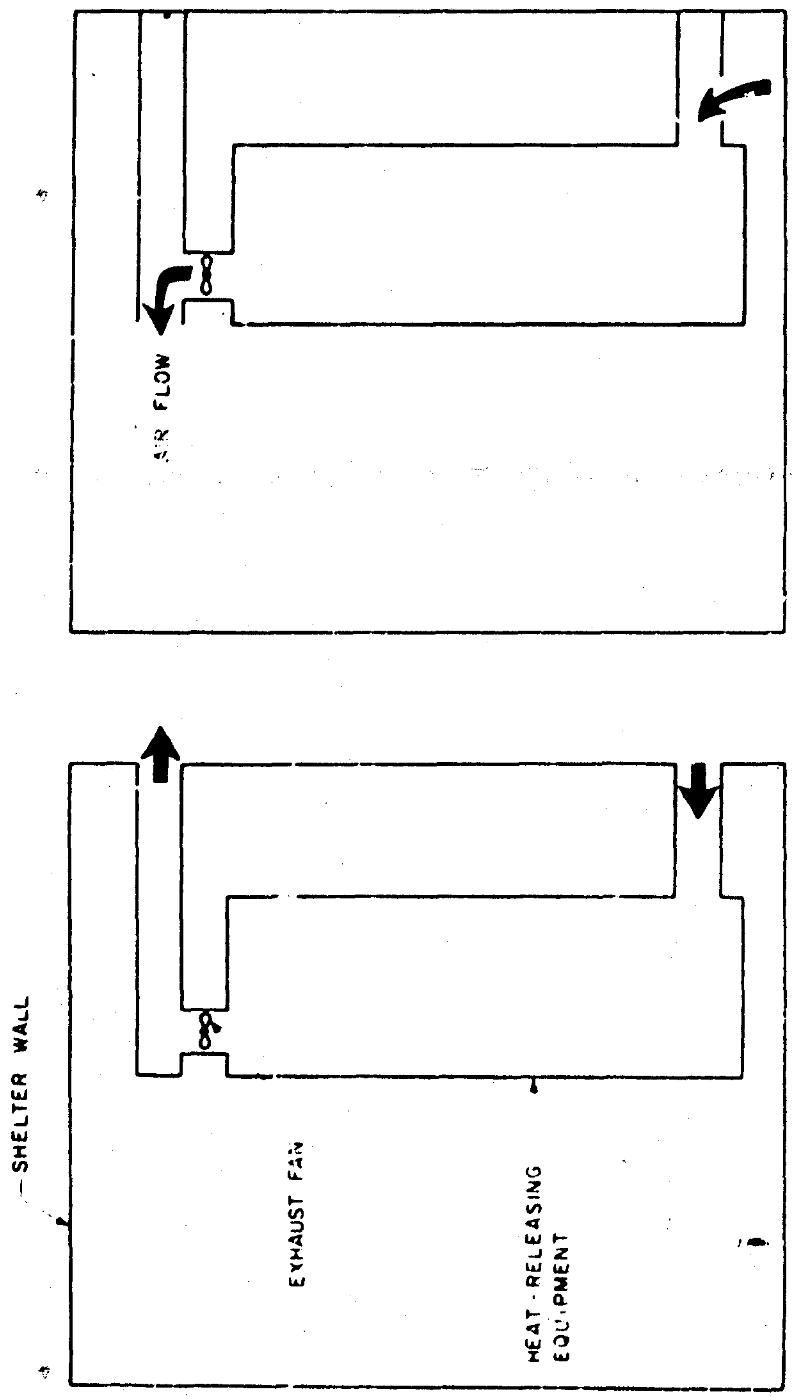
7-4 RECIRCULATION OF AIR FROM HEAT-RELEASING EQUIPMENT

The preceding paragraph has shown how separate ventilation of heat-releasing equipment can reduce the cooling load. The purpose of this paragraph is to show how one can take advantage of heat-releasing equipment to reduce the heating load under cold weather conditions.

To reduce the heating load it is necessary to convey all or part of the heat generated by the equipment to the conditioned space. In some cases it may suffice to deactivate any systems used for separate ventilation of the equipment during warm weather operation; thus, the heat is conveyed to personnel spaces by radiation and free convection. However, if this procedure allows the temperature in some parts of the equipment to rise too high, it will be necessary to make provisions for air from the personnel space to be circulated through the equipment and returned to the personnel space. These procedures are not practicable, of course, if the heat-releasing equipment also gives off unpleasant odors, toxic gases, or other undesirable vapors. Thus, for example, it may be possible to recirculate air through electronic component racks but not through a photo-processing unit.

In applying the technique described, one should take into account the rules of proper air distribution. Air should be removed from and returned to the personnel space without generating undesirably high velocities or any tendency toward stratification.

This and the preceding paragraph show that, to take full advantage of possible reductions in environmental control loads, heat-releasing equipment must be ventilated with outside air during warm weather operation and with inside air during cold weather operation. Fig. 7-2 illustrates such a system. The design should permit easy conversion from one mode of operation to the other. The configuration in Fig. 7-2(B) shows warm air being released into the controlled space at a relatively high elevation. Although it is pre-



(A) Outside air used for warm weather operation

(B) Inside air used for cold weather operation

Figure 7-2. Method of Ventilating Heat-releasing Equipment to Reduce Environmental Control Loads

ferable to release warm air at a low elevation, restrictions imposed by other conditions—such as available space—may sometimes prevent it.

7-5 VENTILATION INDEPENDENT OF ENVIRONMENTAL CONTROL SYSTEM*

When a mobile system is used a large fraction of the time under conditions which require ventilation only—without temperature or humidity control—there may be an advantage in designing the system so that the environmental control unit is bypassed when it is not needed. For a given ventilation rate, the flow resistance through a bypass system would be less than that through the environmental control unit; therefore, less power would be required.

The nature of the bypass system will depend on the application. If the environmental control unit feeds into an air distributing system, the bypass may be designed to feed into the same system. For a small enclosure, it may suffice to provide a wall fan for use when the environmental control unit is not needed. If collective protection is required, the bypass should be designed so that inlet air passes through the collective protection filter unit.

The decision to install a bypass ventilating system depends on the evaluation of several factors. One important factor is an estimate of how often the bypass system would be used and what power savings would be realized. Another consideration is the comparison of installation costs, with and without the bypass. Space is another factor to be considered. In a densely loaded van or shelter it may not be possible to provide space for a bypass, no matter how small the additional space might be.

7-6 EFFICIENT LIGHTING SYSTEM

The heat generated by an inefficient lighting system places an added burden on the air-cooling system. However, it is not always possible to choose the most efficient lighting system because of other factors that must be considered. Although fluorescent lamps have the advantages of high luminous efficiency, low heat generation rate, and long life, they produce objectionable radio-frequency interference unless equipped with specialized shielding. Incandescent lamps are less efficient and have a shorter life under normal operating conditions but they have the advantages that they are not an inherent source of radio-frequency interference and do not produce visible flicker. The acceptability of incandescent lamps is increased by proper louver design. Louvers in a lampshade or housing can enhance natural convection, aiding the dissipation of heat and making it less objectionable for one to be close to an incandescent lamp.

*In a strict sense, the suggestion of this paragraph does not alter cooling or heating loads, but it was considered worthy of mention because it is a way of reducing power requirements.

REFERENCES

1. J. L. Threlkeld, *Thermal Environmental Engineering*, Prentice-Hall, Inc., Englewood Cliffs, N. J., 1962.

2. ASHRAE, *Handbook of Fundamentals*, Amer. Soc. of Heating, Refrigerating and Air-Conditioning Engineers, Inc., New York, N.Y., 1967.

3. R. E. Franseen, *Cooling and Heating Load Calculations for Environmental Control Equipment Applications*, U.S. Army Engineer Research and Development Laboratories, Fort Belvoir, Va., 10 September 1965.

4. U.S. Army Test & Evaluation Command, *Special Study Report of Heating and Cooling Systems of Vans and Shelter-Inclosed Electronics Equipment*, U.S. Army Electronic Proving Ground, Fort

Hauchuca, Arizona, March 1965 (AD-820 730)

5. C. W. Pennington, "How Louvered Sun Screens Cut Cooling, Heating Loads," Heating Piping and Air Conditioning 40(12), 87-90 (1968).

6. C. F. Pickett *Solar Heat Reflecting Coatings*, Paper 690186, Society of Automotive Engineers, New York, N. Y. presented at Intl Automotive Engrg Congress, Detroit, Mich., Jan 13-17 1969.

7. Radio Corp. of Am., *Study Report Electronic Test Set No. 3, Vol 4. Mechanical Considerations* ATF-MTE-L-4, Radio Corp. of Am., Aerospace Systems Div., Burlington, Mass. (AD-476 234)

CHAPTER 8

CRITERIA FOR SELECTION OF ENVIRONMENTAL CONTROL UNITS

8-1 INTRODUCTION

The factors which govern the selection of environmental control units are discussed in this chapter. The primary considerations are the heating and cooling capacities, and the air flow requirements. Following a tentative selection on the basis of these requirements, other factors to be considered include spatial and structural limitations, power and other electrical requirements, and transport considerations.

The general objectives that guide the choice of environmental control units and the design of the environmental control system include:

(1) *Layout Compactness*. The equipment should require as little space as possible, and the arrangement should facilitate efficient performance of the mission. Ref. 1 provides guidance for meeting workspace requirements.

(2) *Operational Flexibility*. It is desirable that the system be adaptable to a variety of missions if this capability can be achieved without sacrificing the primary mission. This characteristic also includes the capability of performing a given mission with a variety of equipment configurations. Therefore, operational flexibility may involve the use of different parts of a system for different missions, as well as interchangeability of components.

(3) *Transportability*. The ease of transportation by truck or tractor should be as great as possible, and it is also desirable that the system be adaptable to other modes of transportation by air, rail, and ship.

(4) *Mobility (Assembly and Disassembly)*. The time required to assemble all components of a system and to put them into operation at a given location should be as short as possible. Similarly, it should take as little time as possible to disassemble a system and prepare it for transportation. This characteristic encompasses the possible reduction of the number of system components that require assembly, the simplification of cable connections and ductwork that must be set up in the field, and the accessibility of auxiliary elements such as power sources.

The final design should be arrived at by consideration of alternative components and configurations, and a selection of the most effective combination in view of the desired characteristics. Under some operational situations the various environmental requirements for personnel and equipment in a given application may not be mutually compatible. The designer must then make adjustments which produce the most effective system within the limitations.

8-2 PERFORMANCE REQUIREMENTS

8-2.1 DETERMINATION OF REQUIREMENTS

The first step in selecting environmental control equipment is to calculate the environmental control requirements. Then one can conduct a search of existing military and, if necessary, commercial units which meet the design requirements. It is best to investigate several design concepts and to choose the one most effective for the application. The evaluation of alternative designs may require a test program to demonstrate which of the concepts is best suited to the requirements. A

practical manner, involving a test program for the evaluation of the environmental control units considered for a given application, is given in Ref. 2.

Par. C-1, Appendix C, outlines the procedure for determining environmental control requirements, and par. C-3, Appendix C, gives an example of air conditioner selection.

Although Army regulations specify (Chapter 1) the requirements to be met by environmental control systems, it is necessary also to take into account any special requirements that might be imposed by the application. For example, the activities which take place in the controlled space may demand more than normal alertness from the operators, and the rate of loss of alertness when exposed to the limiting environmental conditions allowed by Army regulations may be unacceptably high. Another example is provided by activities requiring a special degree of cleanliness which would be incompatible with an environment conductive to high perspiration rates. Under such conditions, one should design not merely for tolerability, but for maintenance of the more ideal conditions needed for the required level of performance.

8-2.2 COMBINED HEATING AND COOLING UNITS VS SEPARATE UNITS

In some cases it is preferable if heating and cooling requirements can be met with a single environmental control unit because the use of separate systems usually complicates the design of the air distribution system. It also complicates the automatic temperature control system, adds to maintenance problems, and increases the logistic support burden. The cost of a unit which combines heating and cooling functions will probably be lower than the cost of separate devices suitable for the same application.

The advantages of units combining heating and cooling do not apply to all circumstances, however. In some applications, heating may not be required at all, and the extra weight, size, and cost of a heating and cooling unit compared to a unit that provides cooling only would be a disadvantage. Even under these circumstances, however, Army regulations would require one to use the standard dual-purpose environmental control units unless adequate justification can be given for specifying a nonstandard unit which provides cooling only. Another type of situation exists when the standard environmental control unit that meets the cooling requirement falls short of fulfilling the heating requirement at extremely low external ambient temperatures. In such cases it may be necessary to supply a supplementary heater. One should also consider, however, whether the low heating capacity could be adequately compensated by outfitting personnel with arctic clothing. This measure would be acceptable only if compliance with human factors requirements could be assured for personnel to perform their tasks while wearing arctic gear. Another possibility, if it is established that a supplementary heater is needed during a large fraction of the operating time, is to choose a heater capable of meeting the entire heating requirement and omitting use of the heater in the cooling unit.

8-2.3 NONSTANDARD UNITS

It is probably feasible to meet all environmental control requirements that are likely to be encountered in mobile military structures by the use of existing environmental control equipment. The situation will improve as more of the units now being planned or under development become available. However, cases may be encountered in which the design could be improved substantially with a new item; and there may also be special environmental control problems which cannot be solved acceptably with any existing equipment. In such cases, it is necessary to prepare specifications for the equipment needed and to initiate procurement in accordance with established military procedures[3,4].

8-3 ELECTRICAL LIMITATIONS

8-3.1 POWER-SUPPLY CHARACTERISTICS

Environmental control units of each capacity rating are usually available in models having different electrical characteristics. Most of the standard units are designed for operation at 208 V, although some smaller units are available in 115-V models. The power frequencies are either 60-Hz (1 or 3 phases) or 400-Hz (3 phase). Most combustion heaters have fans which operate on direct current, at 24 V.

Compared with 60-Hz power sources, 400-Hz sources have the advantages of greater simplicity and higher power-to-weight ratio. Therefore, there has been a trend toward the development and use of 400-Hz equipment and power sources for transportable applications. When a 400-Hz primary source is used, it would be preferable if all of the AC electrical equipment could be operated directly from the source. However, if it is necessary to use some devices that operate from 60-Hz sources only, solid state frequency converters can be installed to convert the 400-Hz primary power to 60-Hz primary power. (A more complete discussion of the relative advantages of different power sources may be found in Ref. 5.)

8-3.2 POWER RATING

Power considerations are an important aspect of selection criteria, and they may sometimes be the deciding factor for the choice of environmental control units. This would be the case, for example, if there were little difference in the heating and cooling performance of the different units under consideration and they differed little in other respects also, except that one of them required substantially less power than the others. Choice of the unit with low power requirements might make it possible to use a smaller primary power unit for the entire system. If the difference in power requirements were not great enough to permit use of a smaller primary source, choice of the environmental control unit with the lowest power requirements would have the important advantage that the primary power unit would then have more excess power capability. This consideration is especially important for newly developed structures which inevitably grow in applications and operational demands after they are used in field operations.

Air conditioners create a large lagging power factor that adds significantly to the load of the primary power source. Although the power factor can be increased by the use of compensating capacitors, these would increase the severity of electrical transients.

8-3.3 ELECTRICAL INTERFERENCE

It is important to determine whether the environmental control units under consideration are likely to create transients of sufficient severity to interfere with electronic apparatus operating from the same power supply. Chapters 4 and 6 discuss the features incorporated into standard military units to prevent electrical interference. Ref. 6 specifies the requirements that must be met by military equipment with regard to the emission of, and susceptibility to, electromagnetic interference.

8-4 PHYSICAL LIMITATIONS

The feasibility of mounting the environmental control equipment in the structure and attaching power cables, control circuitry, fuel lines, and ductwork provide additional criteria for the selection of units.

A review of Chapter 2 will aid in selecting the type of installation most suitable for the application. The information in Chapter 9 will also help in the evaluation of different installation configurations.

Points that need to be considered include

(1) Is space available for the unit?

(2) Which mounting configuration makes the best use of available space?

(3) Is the structure strong enough to support the unit?

(4) Is the unit compatible with the air distributing system?

(5) Will the controls be conveniently accessible?

(6) Can maintenance be performed satisfactorily?

(7) Will noise level of installation interfere with operations?

8-5 TRANSPORTATION LIMITATIONS

8-5.1 MOBILITY

Before a final selection is made, it is necessary to consider how the unit affects the transportability of the structure on which it is mounted. The paragraphs on mobility in Chapter 4 and 6 may be helpful in making this final evaluation. Weight, size, and provision of lift and tie-down devices are among the factors which affect mobility.

From the mobility point of view it would be desirable if the environmental control system required nothing more than routine preparation for transport. This might include such operations as shutting off power, closing fuel lines, closing vents, and covering external components. Such routine preparations will suffice only for units which are permanently mounted on the structure. More time and effort are required to prepare for transport when the environmental control units are mounted remote from the structure. Then it is necessary to dismantle power lines and ductwork and to store these items. The remote unit must itself be prepared for transport. A trailer-mounted unit might not require much effort, but a skid-mounted unit requires that a transport vehicle be available and that provisions be made for loading the unit.

The relative importance of transport considerations, compared to those discussed in preceding paragraphs, depends on the importance of mobility in the given application. The more often transportation is expected to take place, the greater will be the importance of mobility considerations.

8-5.2 VIBRATION

One of the major factors to be considered is vibration — both of the environmental control units and of the transporting vehicle. Compliance with the Military Specifications for vibration provides reasonable assurance that the internal components of environmental control units will withstand the vibration-inducing forces of military transport. The units themselves are usually installed in a structure with fixed attachments rather than with vibration-absorbing connections. However, shock-mounting can be employed in cases where vibrations transmitted from the environmental control unit to the structure and thence to other equipment – would be intolerable. Finally, it is necessary to consider the capabilities of the transporting vehicle. Excessive vibration amplitudes, capable of causing damage to piping and other parts of the installation, may result if the unit is too large for the vehicle.

REFERENCES

1. U.S. Army HEL Standard S-6-66, *Human Factors Engineering Design Standard for Wheeled Vehicles* (prepared by R. F. Chaillet and A. R. Honigfeld), Aberdeen Proving Ground, Maryland, September 1966 (AD-646 681).
2. C. A. Hagberg *Collective Protection for Combat Field Structures, Vol II*, Report No. 3000, Litton Systems, Inc., Minneapolis, Minnesota, September 1966.

3. AR 70-38, *Research, Development, Test and Evaluation of Materiel for Extreme Climatic Conditions*, 5 May 19[illegible]

4. AMCR 701-6, *Logistics Responsibilities Assignment of Environmental Control and Refrigeration Equipment*, 4 April 1968

5. ITT Communication Systems, Inc., *Objective Performance Specification for Transportable Communication Facility*, ITT Communication Systems, Inc., Paramus, N. J., 31 May 1963 (AD-408 314)

6. MIL-STD-461, *Electromagnetic Interference Characteristics Requirements for Equipment*, 31 July 19[illegible]

CHAPTER 9

INSTALLATION GUIDES

9-1 INTRODUCTION

The purpose of this chapter is to provide some guidance for the installation of environmental control units, ductwork, and other auxiliary equipment where needed. Some of the information, such as the paragraphs on mounting design, applies primarily to air conditioners, but most of it has general applicability. It is assumed that the requisite environmental control units have been selected; but in cases where one has a choice between several suitable systems, this chapter on installation may help in making the final selection between competitive systems.

In addition to the paragraphs on the mounting of environmental control units and the design and installation of ductwork, other topics covered include air circulation and distribution, controls, safety considerations, maintenance provisions, and noise control.

Human Engineering Laboratories Standards[1] may be consulted for additional design guidance on work spaces, environmental requirements, maintenance provisions, and other topics pertinent to installations in military structures. Manufacturers of environmental control units sometimes include installation data in their publications, such as Ref. 2.

9-2 GENERAL ARRANGEMENT OF ENVIRONMENTAL CONTROL SYSTEM

9-2.1 CHOICE BETWEEN FREE DISCHARGE AND DUCT SYSTEM

Most military shelters and other small mobile structures are small enough so that little, if any, ducting is needed for proper air distribution. However, military vans and large structures do require ductwork.

There are cases in which the environmental control requirements can be met by a combination of free discharge and the use of ductwork. This situation may arise, for example, if the personnel area is small enough to be ventilated properly without use of ductwork, while there may be equipment cooling requirements which can be met more efficiently by ducting air directly from the air conditioner to the equipment (and exhausting directly to the atmosphere). In such cases, the capacity of the unit must equal the total load, and an appropriate fraction of the outlet grille is ducted to the equipment to be cooled.

9-2.2 LOCATION OF ENVIRONMENTAL CONTROL UNITS

One of the first things to be decided in planning an installation is the location of the environmental control unit. Some of the factors that must be considered are indicated in the paragraphs which follow. It will be helpful to review Chapter 2, which describes air conditioner installations. It will also be helpful to consult other paragraphs of this chapter in which the factors mentioned below are discussed in detail.

(1) *Air Circulation*. The way in which this factor affects the location of the environmental control unit depends mainly on whether the conditioned air is to be delivered through free discharge from the unit or through a duct system. When using the free-discharge method, the unit must be located so that the air will circulate where required without exposing personnel to high-

velocity air streams. It is desirable that air velocities around personnel be less than 50 ft/min, and velocities should not exceed 100 ft/min. When a duct system is used, the unit may be located in a relatively unexposed position governed by the design of the duct work.

(2) *Compatibility with Location of Other Equipment.* Vans, shelters and other mobile systems are usually loaded with equipment, thus restricting the location of the environmental control unit. It is highly desirable that the environmental control engineer participate in the design of the whole system so that environmental control considerations will receive due attention along with the functional requirements of the equipment and the personnel operating it. This is particularly true if the equipment itself requires temperature control (or any other type of environmental control). It is usually necessary to trade-off optimum electronic equipment location with climate control equipment requirements.

(3) *Maintenance.* The environmental control unit should be located so that maintenance, particularly the routine tasks, can be performed as conveniently as possible.

(4) *Noise Control.* Occasionally it is possible to achieve a measure of noise control simply by the judicious location of the environmental control unit. For example, one should avoid locating the unit near an area where personnel will be working — the farther the unit is from work areas, the easier it will be to reduce the noise to an acceptable level.

9-2.3 TYPICAL SYSTEM LAYOUTS

Fig. 9-1 illustrates five trailer-type applications of environmental control systems. In the arrangement of Fig. 9-1(A), ductwork is used to bring cool air directly from the air conditioner to equipment and work areas which require cooling; air which has passed through the equipment racks mixes with air in the work areas and returns to the environmental control unit by way of a passageway. A disadvantage of this arrangement is that the heated air leaving the racks enters the personnel areas, thereby tending to increase the cooling load. Furthermore, heated air tends to rise, but in this arrangement the warm return air is expected to move horizontally at a low level. A better arrangement is shown in Fig. 9-1(B). Here, the supply air enters the personnel area through a perforated ceiling, enters equipment racks at the bottom, and flows upward through them into the return air ducts. The arrangement shown in Fig. 9-1(C) is similar to the one in Fig. 9-1(B) except that the division of the space above the perforated ceiling into separate compartments supplied by individual ducts helps to guarantee uniform delivery of supply air. The arragement shown in Fig. 9-1(D) is suitable when the space to be conditioned is relatively open instead of being obstructed by equipment. The perforated ceiling helps to distribute the supply air evenly, and the natural tendency of the cool air to move downward supports circulation. The arrangement in Fig. 9-1(E) is a variant of the one in Fig. 9-1(B) with the air used to cool the equipment racks exhausted directly to the outside. This is better than recycling the air when the temperature rise through the equipment racks is so high that it would increase the required cooling capacity of the environmental control units.

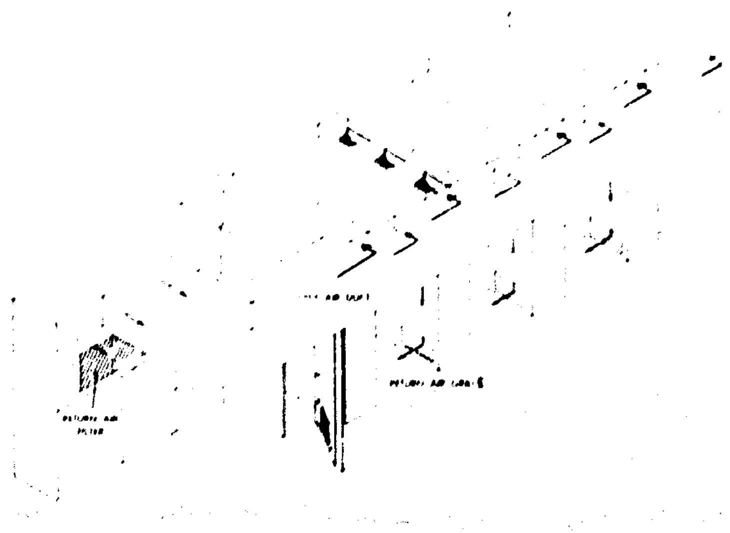
Figs. 9-2 and 9-3 show typical heating and air-conditioning installations in a semi-trailer, the first with vertical heat ducts, the second with horizontal heat ducts. Cooling air is supplied through a perforated ceiling and returns through the heat ducts.

9-3 MOUNTING DESIGN

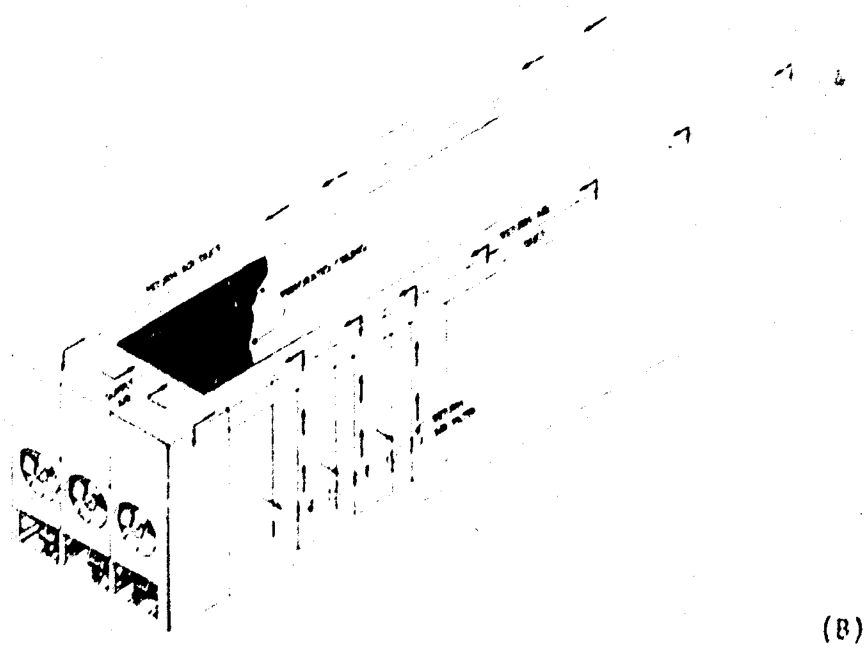
9-3.1 TYPES OF MOUNTING

9-3.1.1 INTRODUCTION

The various types of environmental control unit installations were illustrated and discussed in Chapter 2. In this paragraph, mounting and attachment methods are covered in

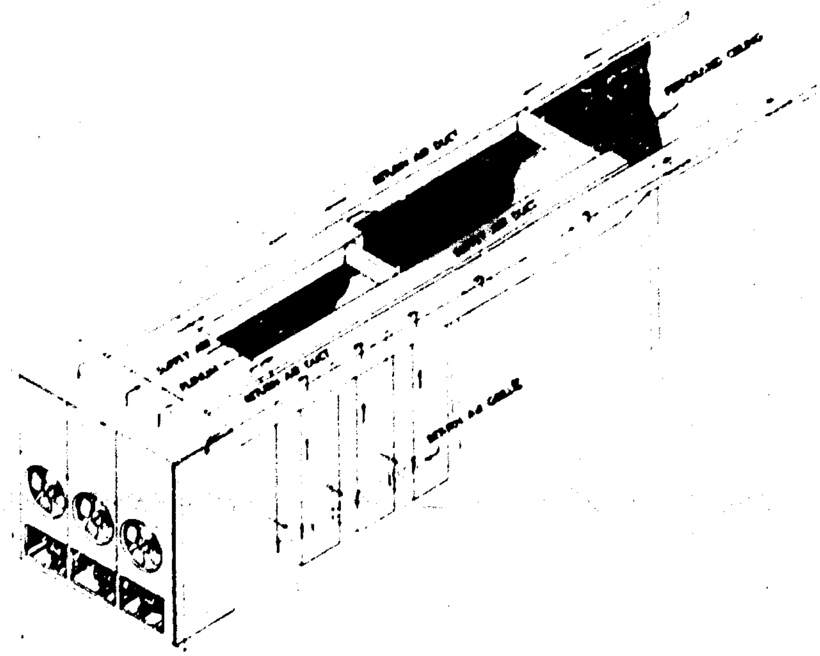


(A)

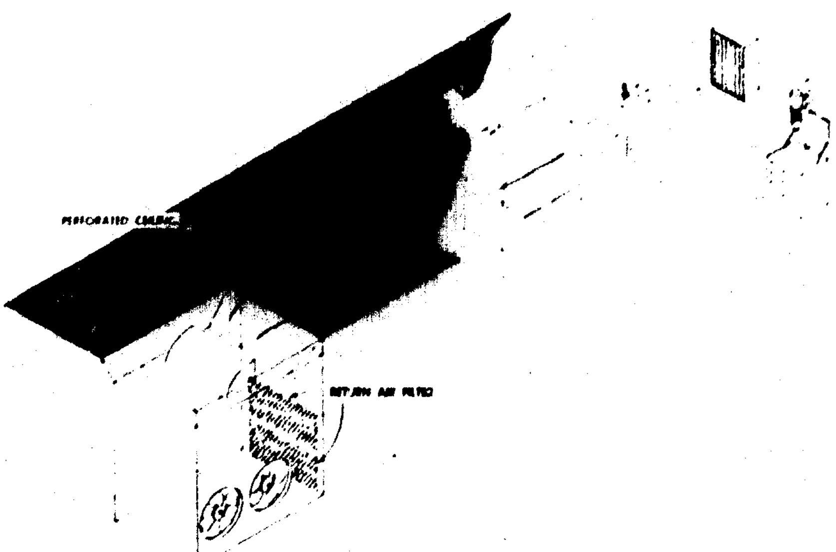


(B)

Figure 9-1. Typical Air Distribution Arrangements for Trailers (1 of 3)
(Courtesy of Ellis and Watts Co.)



(C)



(D)

Figure 9-1. Typical Air Distribution Arrangements for Trailers (2 of 3)
(Courtesy of Ellis and Watts Co.)

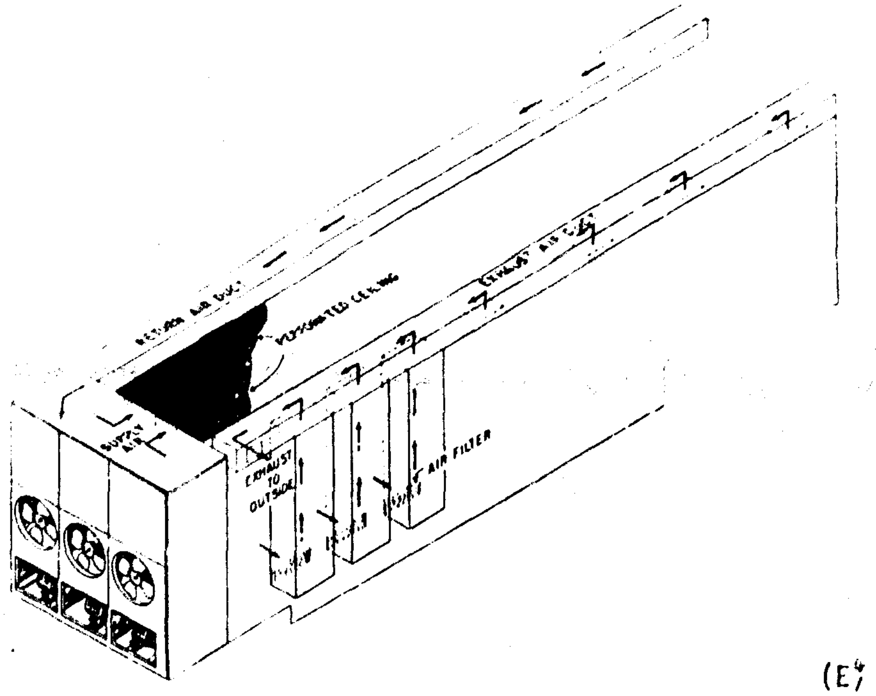


Figure 9-1. Typical Air Distribution Arrangements for Trailers (3 of 3)
(Courtesy of Ellis and Watts Co.)

greater detail. For convenience, the structure being controlled is often referred to as a shelter; but it should be clear that most of the information is applicable to other mobile structures also, such as vans and trailers.

9-3.1.2 THROUGH-THE-WALL MOUNTING

Fig. 9-4 illustrates a type of mounting suitable for relatively small, one-piece units. The unit is held firmly in place by a frame which surrounds the unit at the wall of the shelter and a bracket which supports the external overhang. It is necessary to cut a hole in the wall large enough for the entire unit to pass through. Condensate is removed by a tube connected to one of the drain connections which, in units of the compact family (Table 3-1), are located on the front, back, and sides. This type of mounting is also shown in Fig. 7-1.

Fig. 9-5 shows a method of installation, applicable to small integral air-conditioning units, in which the mounting is made through the shelter door. This type of mounting provides free access to the unit for maintenance, and it frees wall space for other uses. The door hinges must be properly designed to provide adequate support for the additional weight of the environmental control unit; otherwise, the door will eventually be distorted. Objections to this type of installation are that it is cumbersome to open and close the door, and the electrical power cable may become fatigued by repeated bending.

9-3.1.3 EXTERIOR MOUNTING

Exterior mounting is most commonly used in larger shelters, where the environmental control units may be heavy and bulky, and it is nonetheless desirable to transport them as an integral part of the shelter. The maximum permissible width of vehicles for the various modes of transportation generally limits exterior installation of environmental equipment to the front or back of the shelter. The units also can be supported on a platform attached to the outside wall of the shelter.

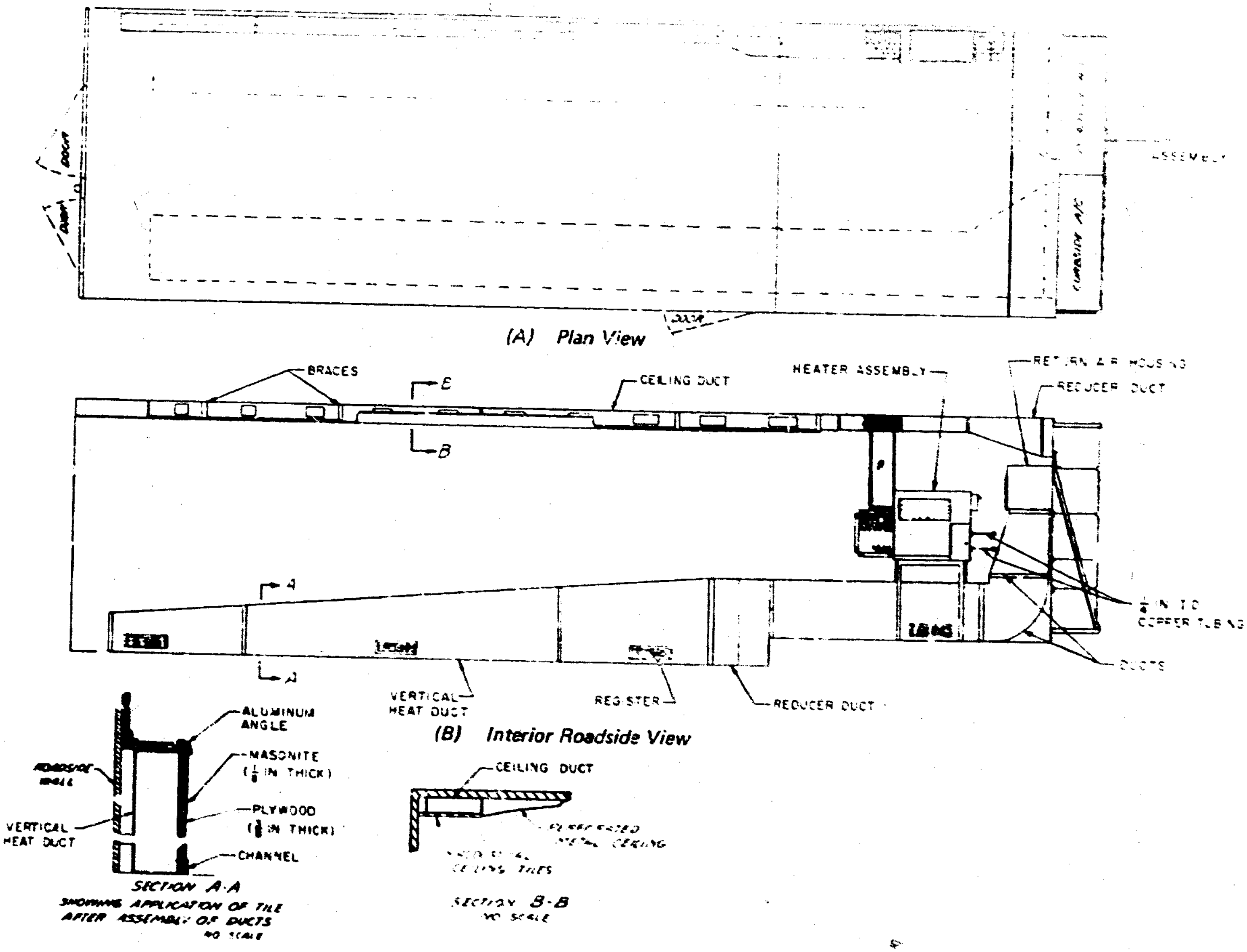
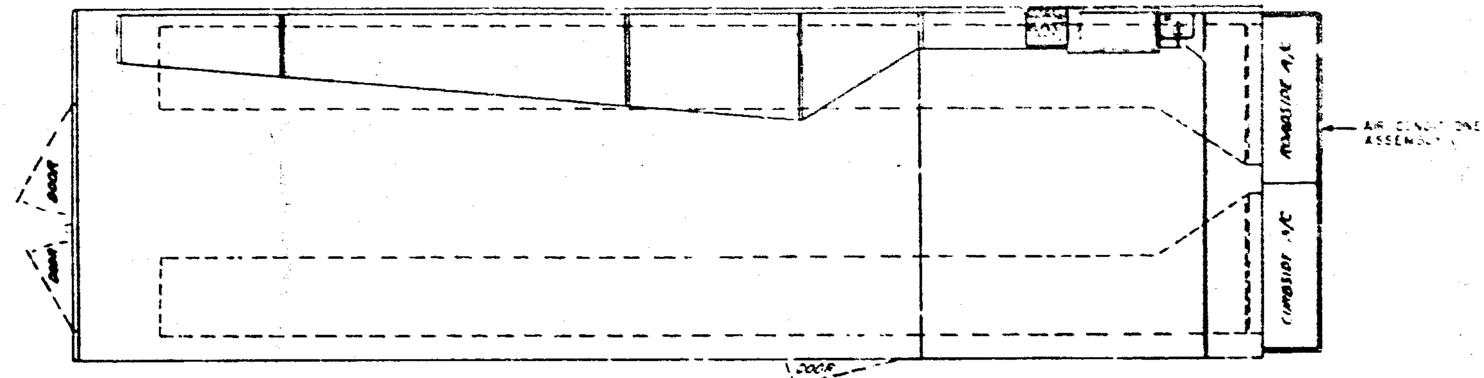
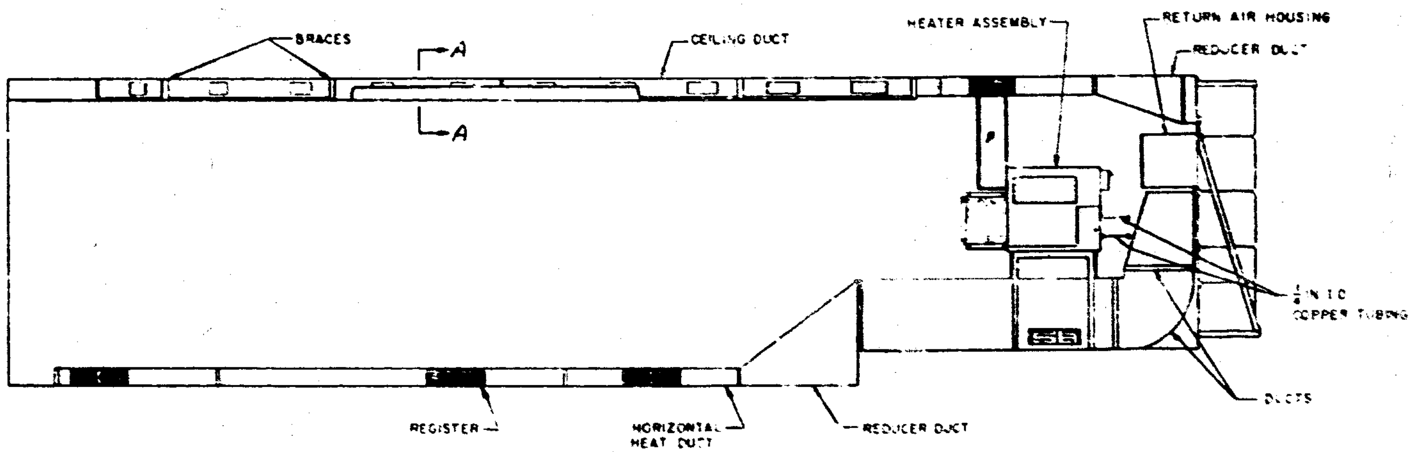


Figure 9-2. Typical Heating and Air-conditioning Installation in Semi-trailer Using Vertical Ducts
(This drawing does not necessarily represent the latest design techniques and is shown for information only.)



(A) Plan View



(B) Interior Roadside View

Figure 9-3. Typical Heating and Air-conditioning Installation in Semi-trailer Using Horizontal Ducts
(This drawing does not necessarily represent the latest design techniques and is shown for information only.)

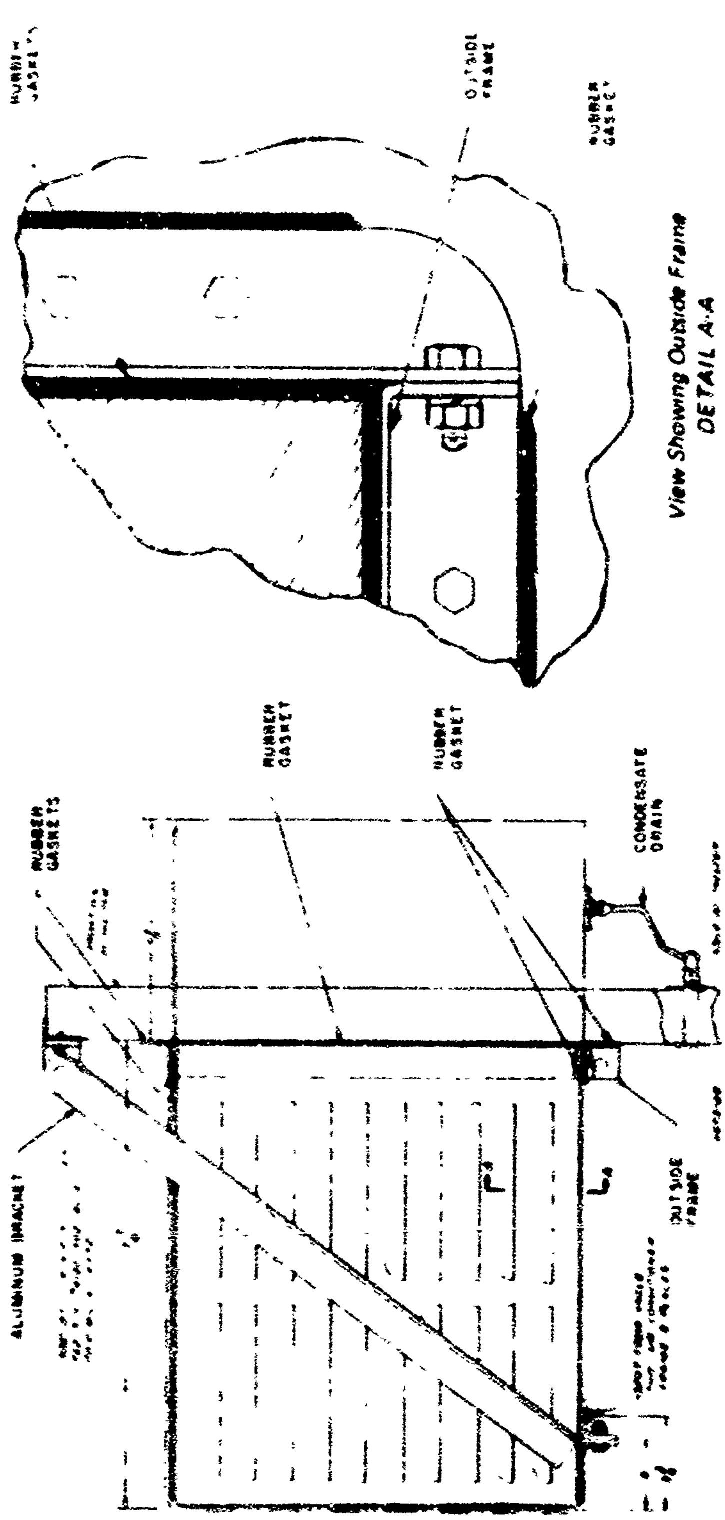


Figure 9-4. Through-the-wall Installation of Air Conditioners

(This drawing does not necessarily represent the latest design techniques and is shown for information only.)

Figure 9-5. Door-mounted Environmental Control Unit[2]
(Courtesy of Trane Company)

Openings are cut in the shelter wall for supply and return air connections as required. The trailer nose installation as shown in the middle photograph of Fig. 2-7 is typical.

Fig. 9-6 illustrates an exterior mounting, in which the frame is hinged, permitting the units to be swung out 90 deg for servicing.

Fig. 9-7 illustrates the exterior mounting of a large air conditioner which is enclosed by a detachable frame.

9-3.1.4 INTERIOR-EXTERIOR MOUNTING

Environmental control units of multiple-unit design can be mounted with the evaporator section inside the shelter and the condenser section outside the shelter. An advantage of this arrangement is that only relatively small holes need be cut in the shelter wall; holes are needed for the fresh air inlet and the refrigerant lines and power cables. This type of mounting is illustrated in Figs. 9-8, 9-9, and 9-10.

Several views of an interior-exterior mounting of a five-section multiple unit are shown in Fig. 9-11(A, B, and C). Fig. 9-11(A) also illustrates the floor mounting of a heater.

9-3.1.5 RETRACTABLE MOUNTS

A special type of through-the-wall mounting employs a telescoping rail support, as shown in Fig. 9-12, which permits the unit to be retracted into the shelter. The clearance between the unit and the shelter can be closed by a flexible canvas or rubber boot. If the unit is connected to ductwork, a flexible or removable section must be provided to accommodate the movement of the unit. This arrangement permits the shelter users to move the environmental control unit outside the shelter when in use, thus freeing usable space inside the shelter. When not in use, and when in transit, the unit may be retracted into the shelter and the opening covered by a door or flap.

Another example of a retractable mounting is shown in Fig. 2-3.

9-3.1.6 HEATER MOUNTING

The mounting of heaters in mobile structures is usually quite simple. In most cases, the heating unit is mounted inside the structure, either resting on the floor or on a convenient shelf. Several heater installations were illustrated in Figs. 2-1 and 2-2. Additional examples are given here in Figs. 9-13 through 9-17. These show more clearly the use of brackets to keep the units in place; they also illustrate fuel, exhaust, and power connections.

9-3.2 VIBRATION CONTROL

It is estimated that 99% of all air conditioners used in mobile military structures are hard-mounted. Antivibration provisions within the air conditioners reduce the intensity of vibrations transmitted to the structure, so that there usually is no interference with satisfactory operation of other apparatus mounted in the structure. However, rubber gasketing is frequently used because it is convenient to apply and it does reduce vibration to some extent.

In the case of through-the-wall mountings,

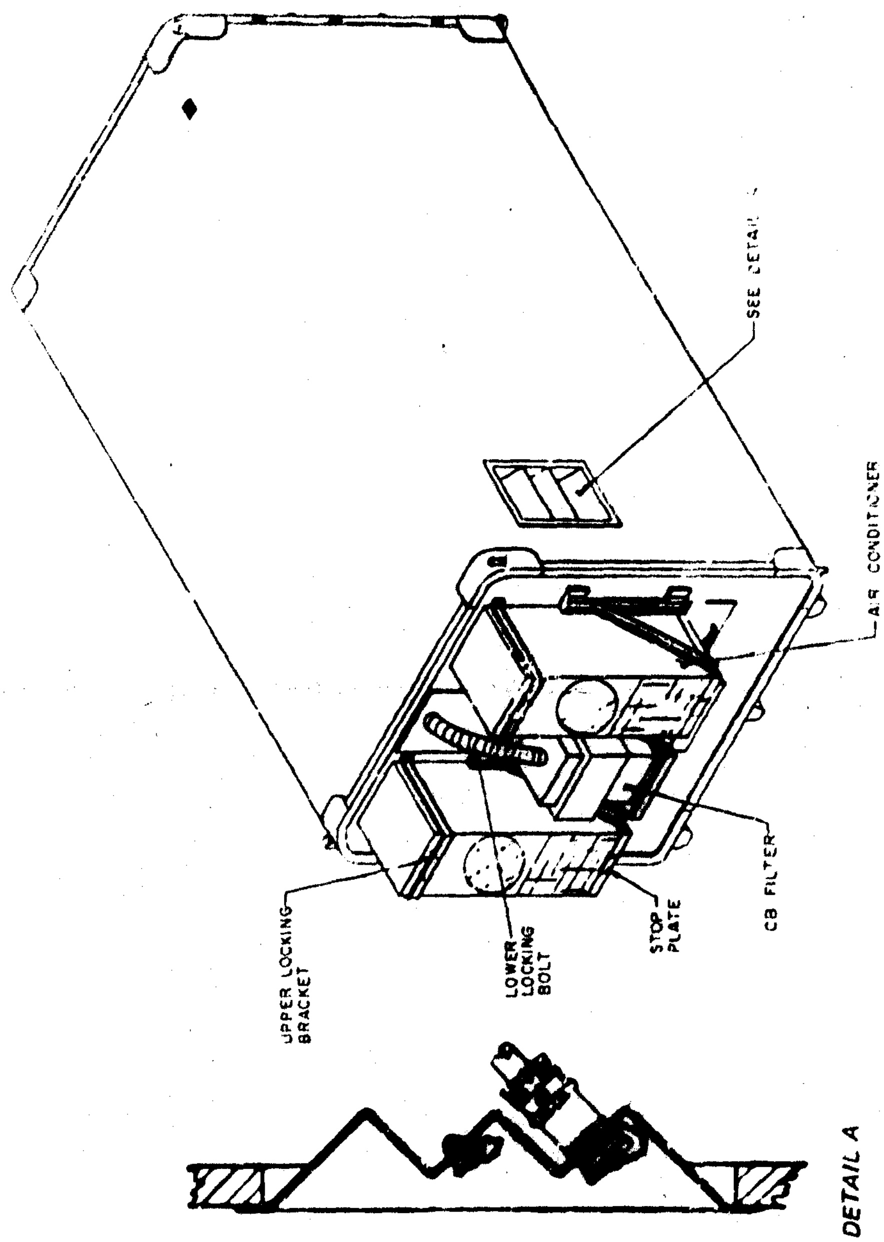


Figure 9-6. Hinged Air Conditioner Mounting Which Permits Swinging Out for Servicing

(This drawing does not necessarily represent the latest design techniques and is shown for information only.)

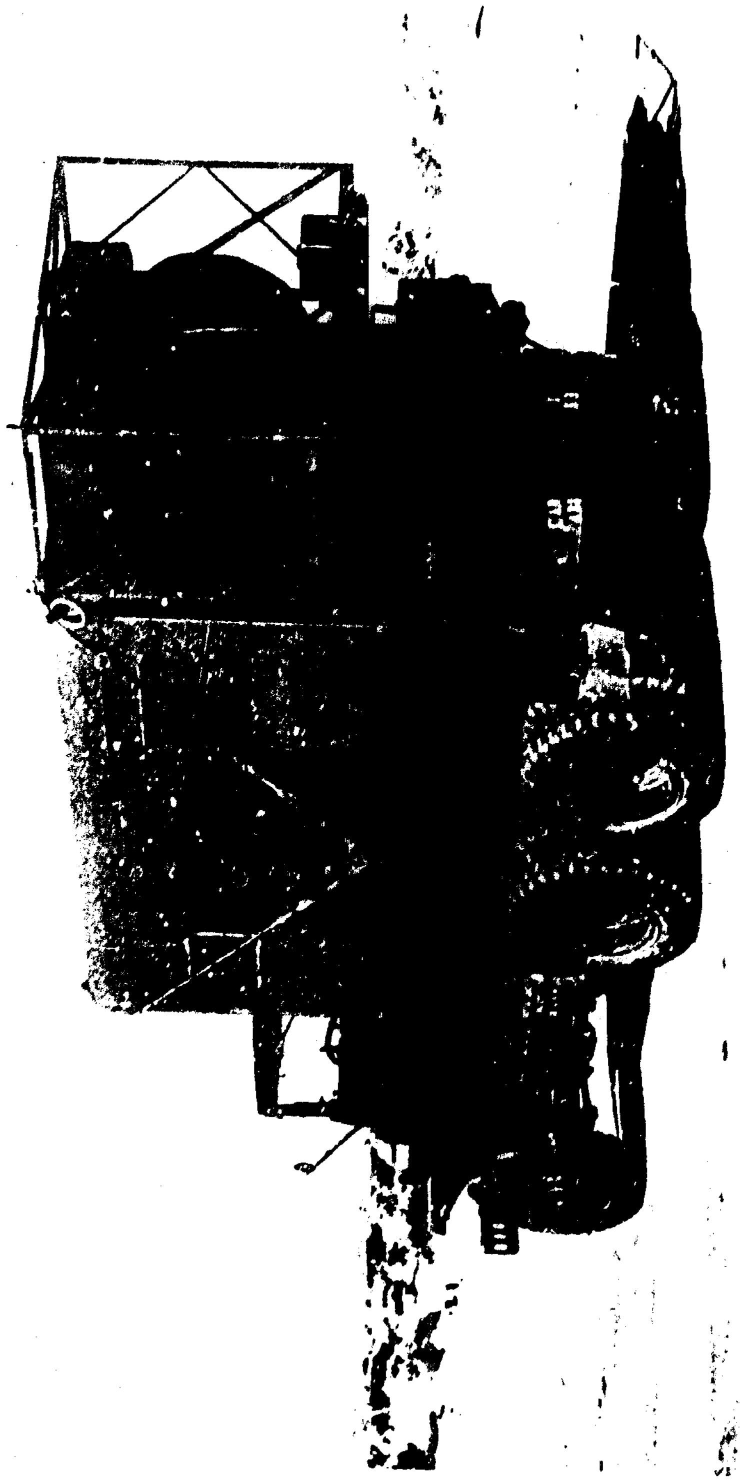


Figure 9-7. Large Air Conditioner Mounted on Van With Detachable Frame

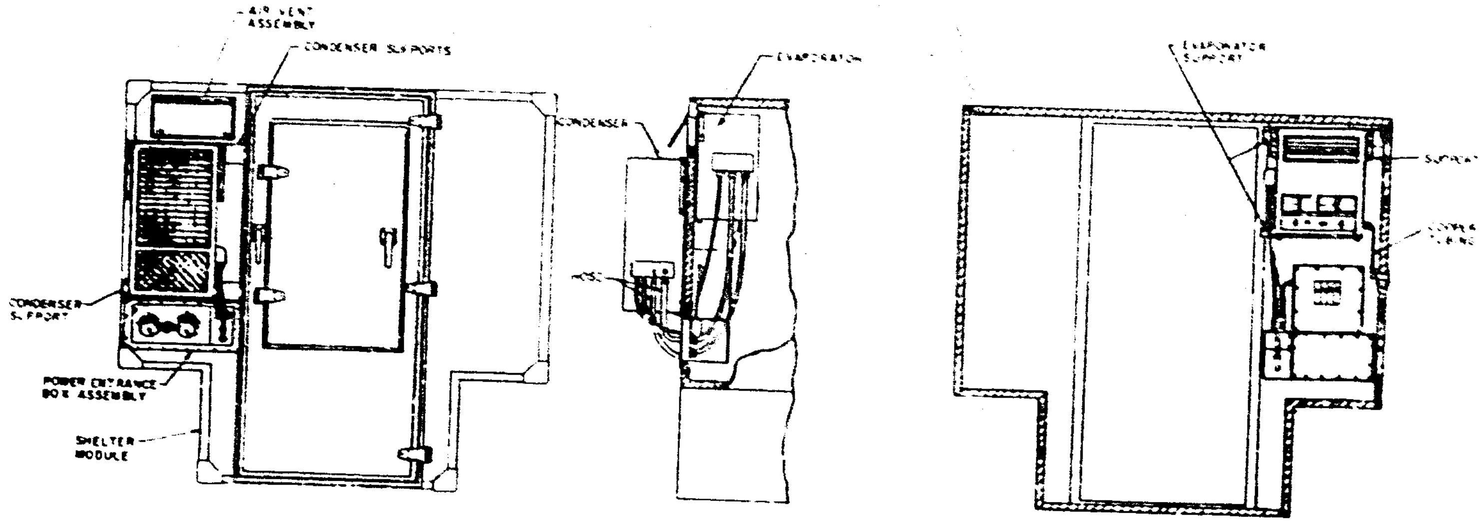


Figure 9-8. Installation of Multi-unit Air Conditioner

(This drawing does not necessarily represent the latest design techniques and is shown for information only.)

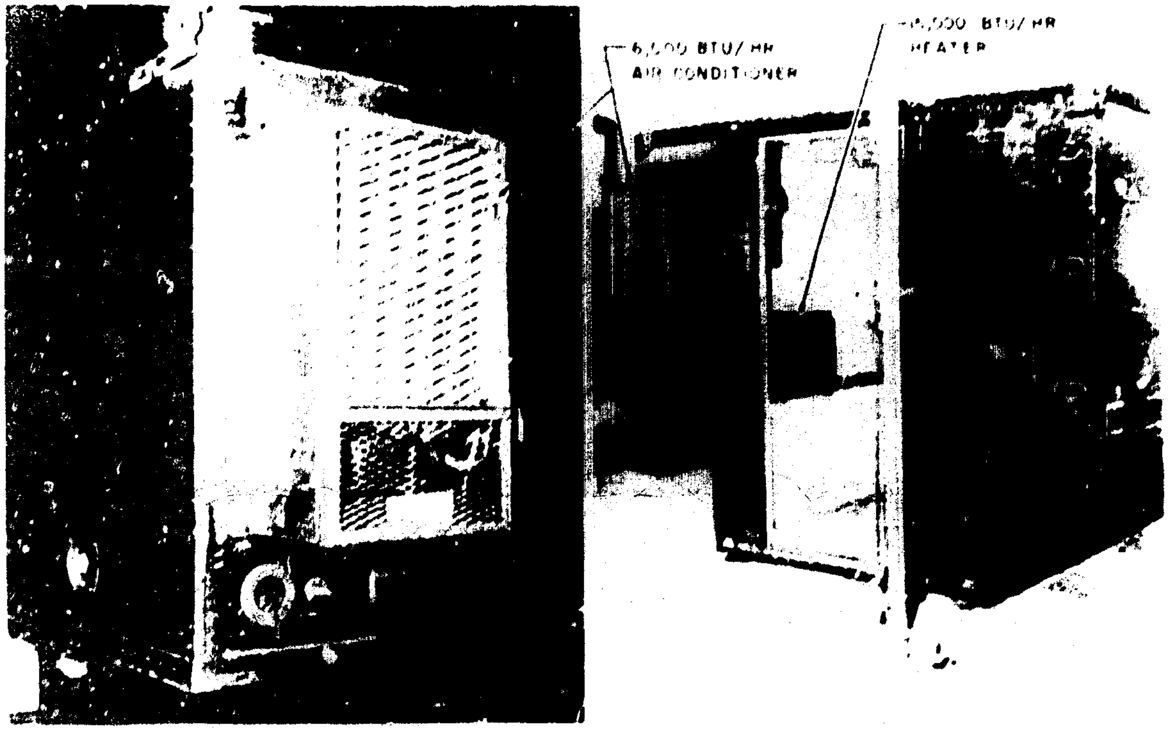


Figure 9-9. Wall-mounted Heater and Air Conditioner in Shelter

(This photograph is for information only and should not be used as a criterion for the design of similar installations.)

a clearance between the outside enclosure of the environmental control unit and the hole through which it passes helps to prevent the transmission of vibration to the shelter structure. This is illustrated in Fig. 9-18. The unit is centered in the hole and bolted to the floor of the shelter or onto a platform provided for the purpose. The opening may be sealed, as shown, by use of an aluminum or steel angle and rubber gasketing. When units are mounted on a frame attached to the shelter wall, a vibration absorbing gasket should also be used between the bottom of the unit and the top of the frame, as indicated in Fig. 9-4.

9-3.3 EXTERNAL CONNECTIONS

9-3.3.1 ELECTRICAL CONNECTIONS

Military environmental control units are provided with power cables or terminals which can be conveniently connected to the power source. In the case of air conditioners, power cables are usually attached to the back of the unit with MIL-STD connectors, but alternative connections are also available at the sides of the unit.

The control panel, which is mounted in the front of air-conditioning units, may be removed for remote mounting. Control cable assemblies are available for extending the control circuits from the unit. If the control panel is removed for remote mounting, the opening should be closed with a block-off plate provided for the purpose. Also, the sensing bulb of the thermostat must be placed in the return air stream.

When making interior-exterior installations of units designed to be installed with the evaporator section inside the shelter and the condenser section outside, power connection between the two components is made with MIL-STD connectors. This is illustrated in Figs. 9-8 and 9-10. Fig. 9-19 illustrates how

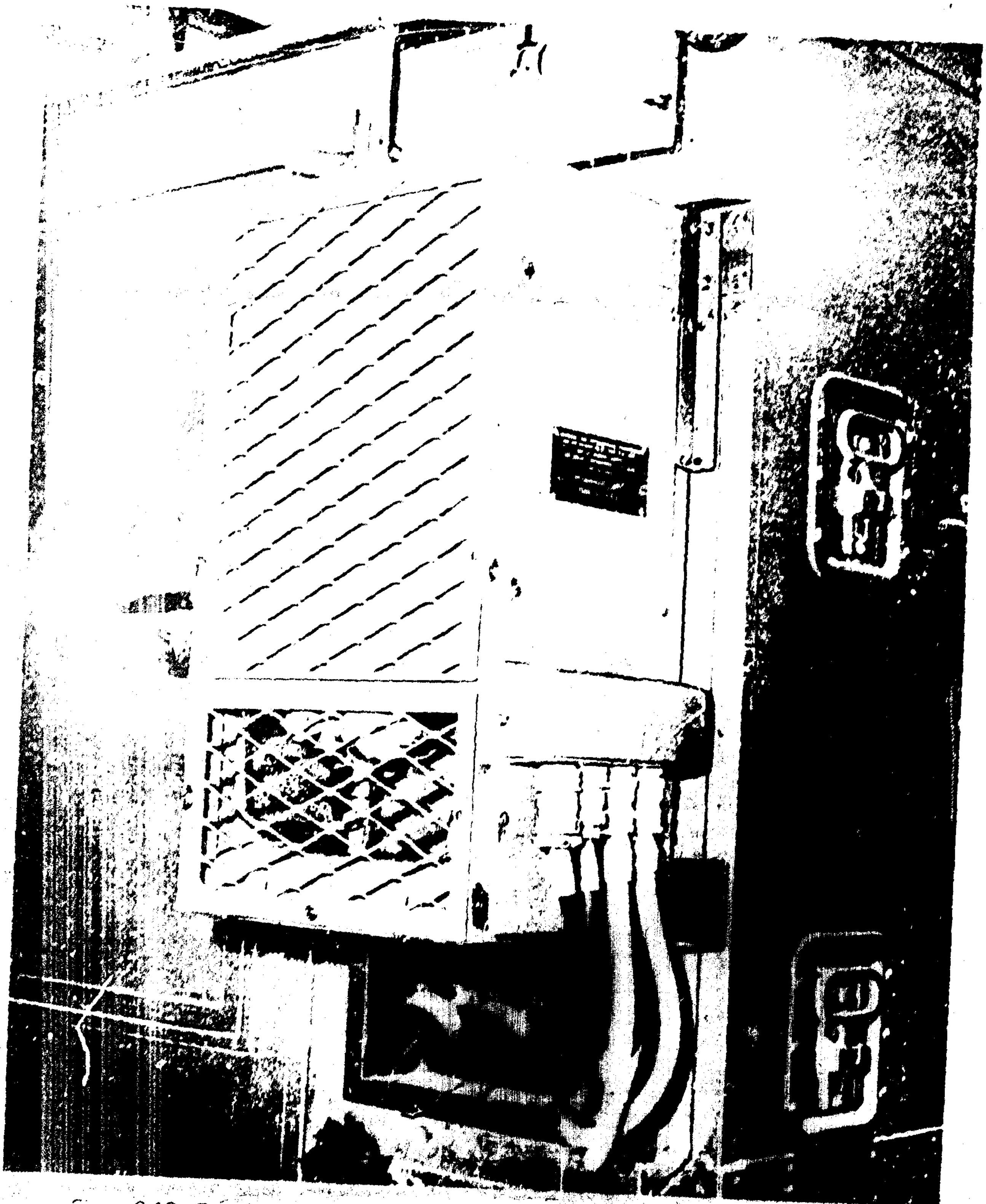


Figure 9-10. Exterior Mounting of Condenser Section of 6,000 Btu/hr Air Conditioner Showing Power Cables and Refrigerant Lines

(This photograph is for information only and should not be used as a criterion for the design of similar installations.)

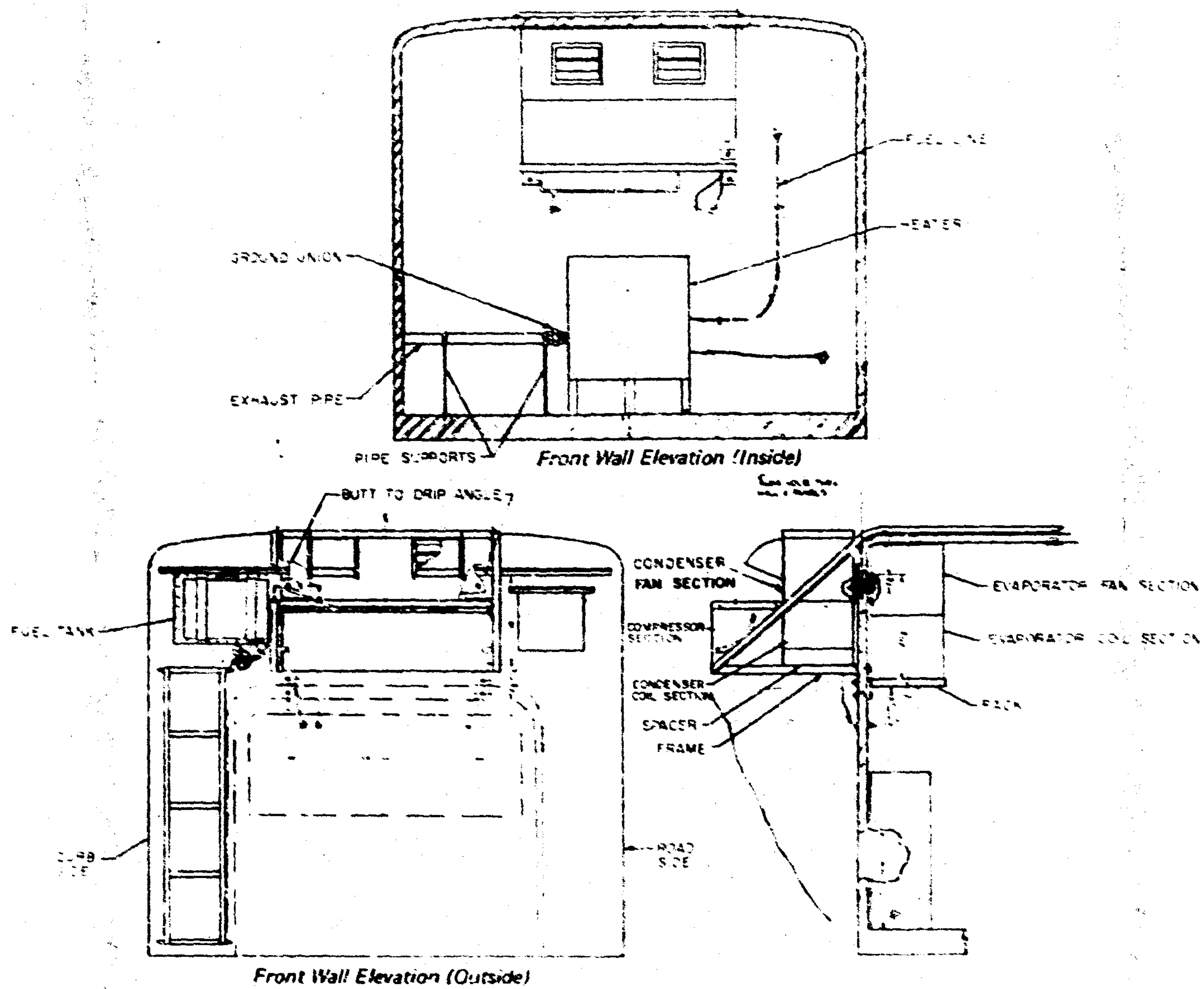


Figure 9-11(A). Elevation Views of Air Conditioner and Heater Installation in Shop Van

(This drawing does not necessarily represent the latest design techniques and is shown for information only.)

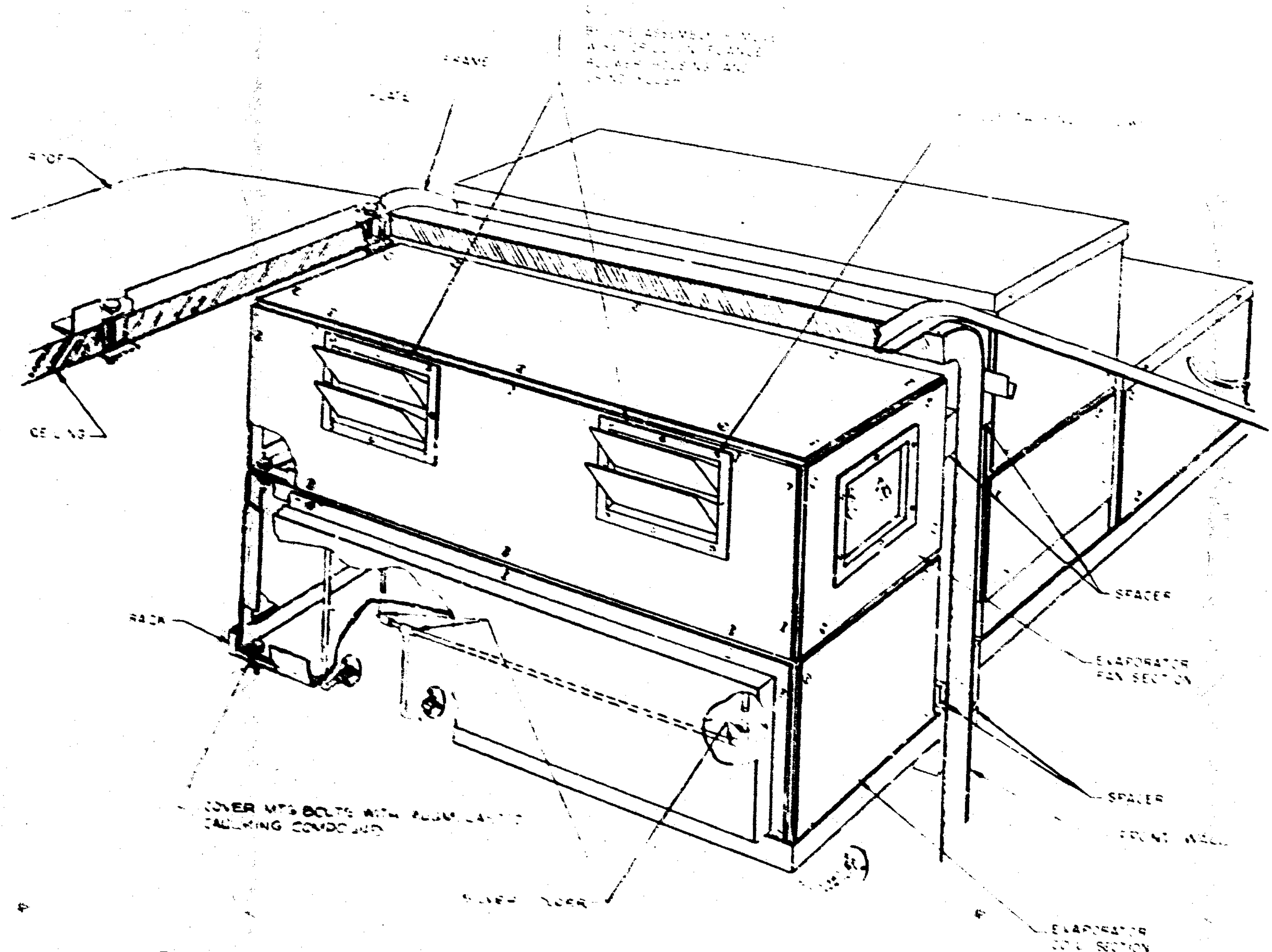


Figure 9-11(8). Inside Isometric View of Air Conditioner and Heater Installation in Shop Van
(This drawing does not necessarily represent the latest design techniques and is shown for information only.)

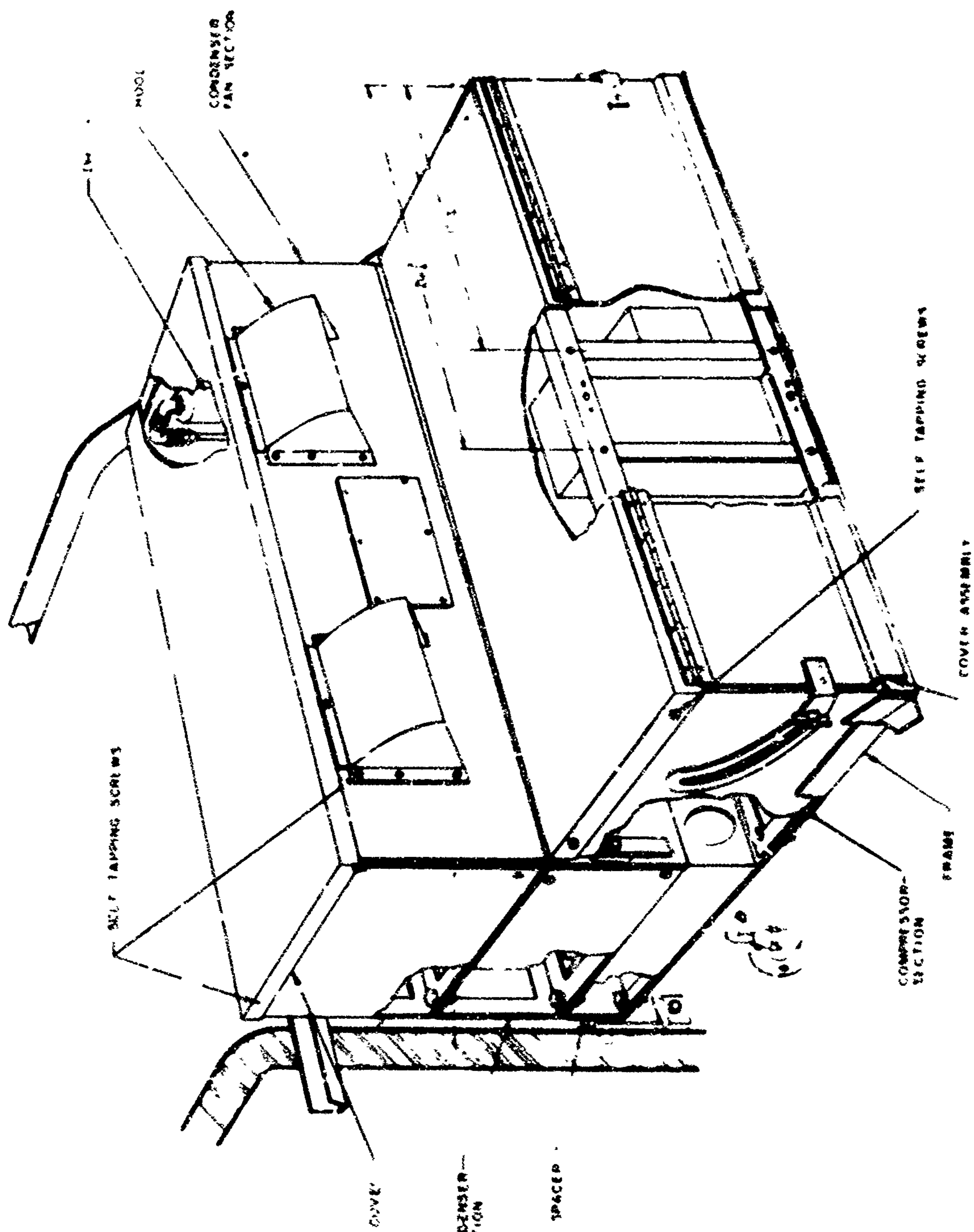


Figure 9-11(C). Outside Isometric View of Air Conditioner and Heater Installation in Shop Van
(This drawing does not necessarily represent the latest design techniques and is shown for information only.)

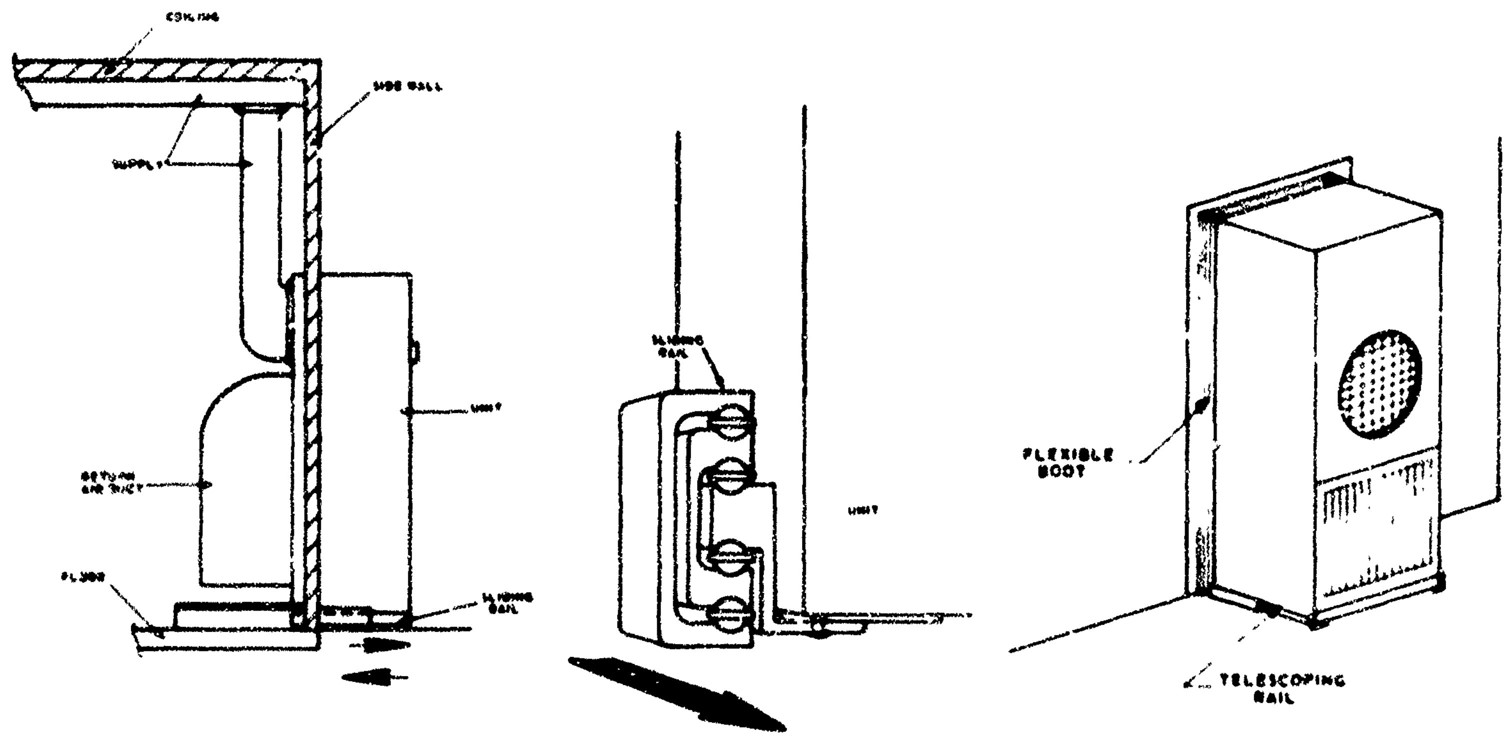


Figure 9-12. Telescoping Rail Installation[3]

(Courtesy of Trane Company)

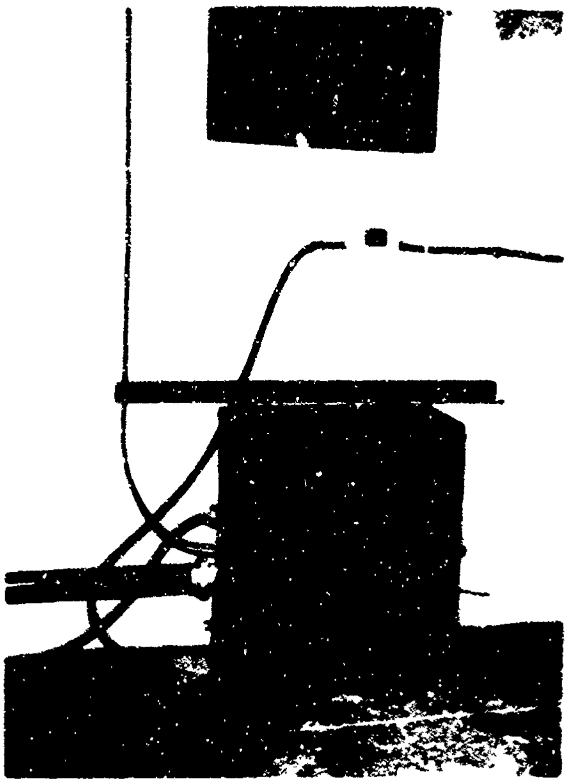


Figure 9-13. Heater Mounted on Floor of Shelter

(This photograph is for information only and should not be used as a criterion for the design of similar installations.)

the power cable can be passed between the condenser fan and evaporator fan sections for the type of installation shown in Fig. 9-11.

In Ref. 4 it is recommended that power-generating equipment be located exterior to shelters instead of being made an integral part of them. Internal location of power units would increase the difficulty of controlling noise, vibration, and toxic fumes. Other contributing factors are space limitations, logistics, cost, and the rel ve difficulties of providing fuel-supply and engine-exhaust systems. When several pieces of electrical equipment (e.g., air conditioner, heater, CB filter unit) must be connected to an exterior power supply, consolidation of controls into a common control box will simplify cabling which must be passed through the shelter wall and conserve space inside the shelter.

9-3.3.2 CONDENSATE DRAIN

A condensate drain tube should be connected between air-conditioning units and the exterior of the shelter. A trap should be included next to the unit, as shown in Fig. 9-20. If there is only one condensate drain, the connection should be made to it. If there is more than one condensate drain as in the case of vertical compact units, the connection should be made to at least three of the four drains provided.

Depending on the climatic conditions and the size of the unit, the amount of condensate may be considerable – measured at the rate of 10's of gallons per 24 hr of operation.

9-3.3.3 FUEL AND EXHAUST CONNECTIONS

(1) *Fuel Connections.*

Fuel tanks for combustion heaters should be so located as to avoid loading the fuel pump unnecessarily. The distance between the tank and the pump should be as short as possible and the connection tube should be of adequate diameter. In particular, the tank should not be too low with respect to the fuel pump. If it is located above the heater, the tank should have a top outlet, which should be provided with an anti-siphon device. If two heaters, each having its own fuel pump, are connected through a tee to a common line from the fuel tank, the line between the pumps should be of adequate diameter to prevent the operation of one pump from interfering with the operation of the other. With a tee arrangement, if the line between pumps is too small, it is possible for the operation of one pump to prevent functioning of the other.

Fuel intake fittings should not protrude from wall exteriors where they are highly susceptible to damage during loading, unloading, and transport. Detail A in Fig. 9-6 illustrates a method of recessing the connections.

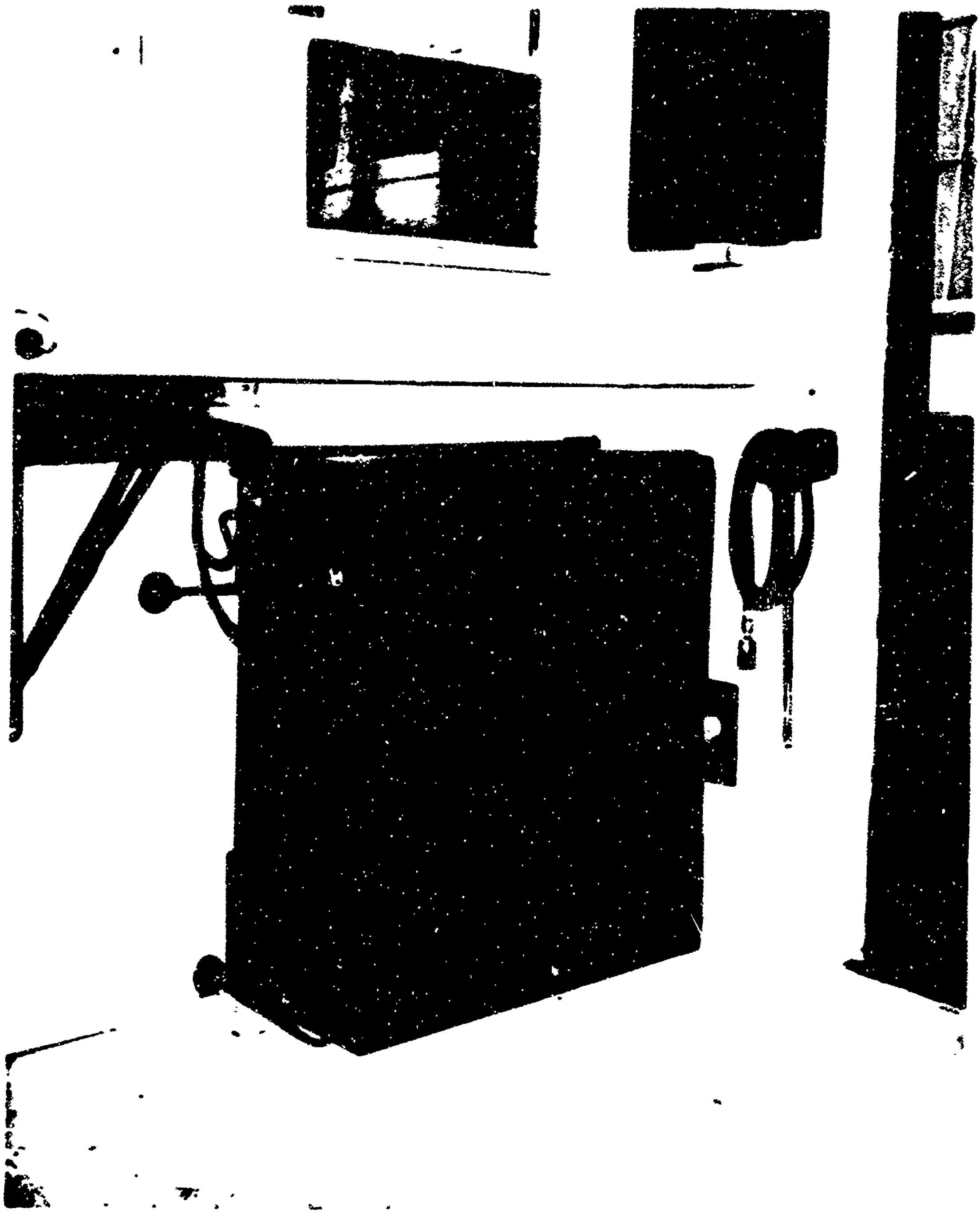


Figure 9-14. Floor-mounted Space Heater With Quick-disconnect Fuel Adapter

(This photograph is for information only and should not be used as a criterion for the design of similar installations.)

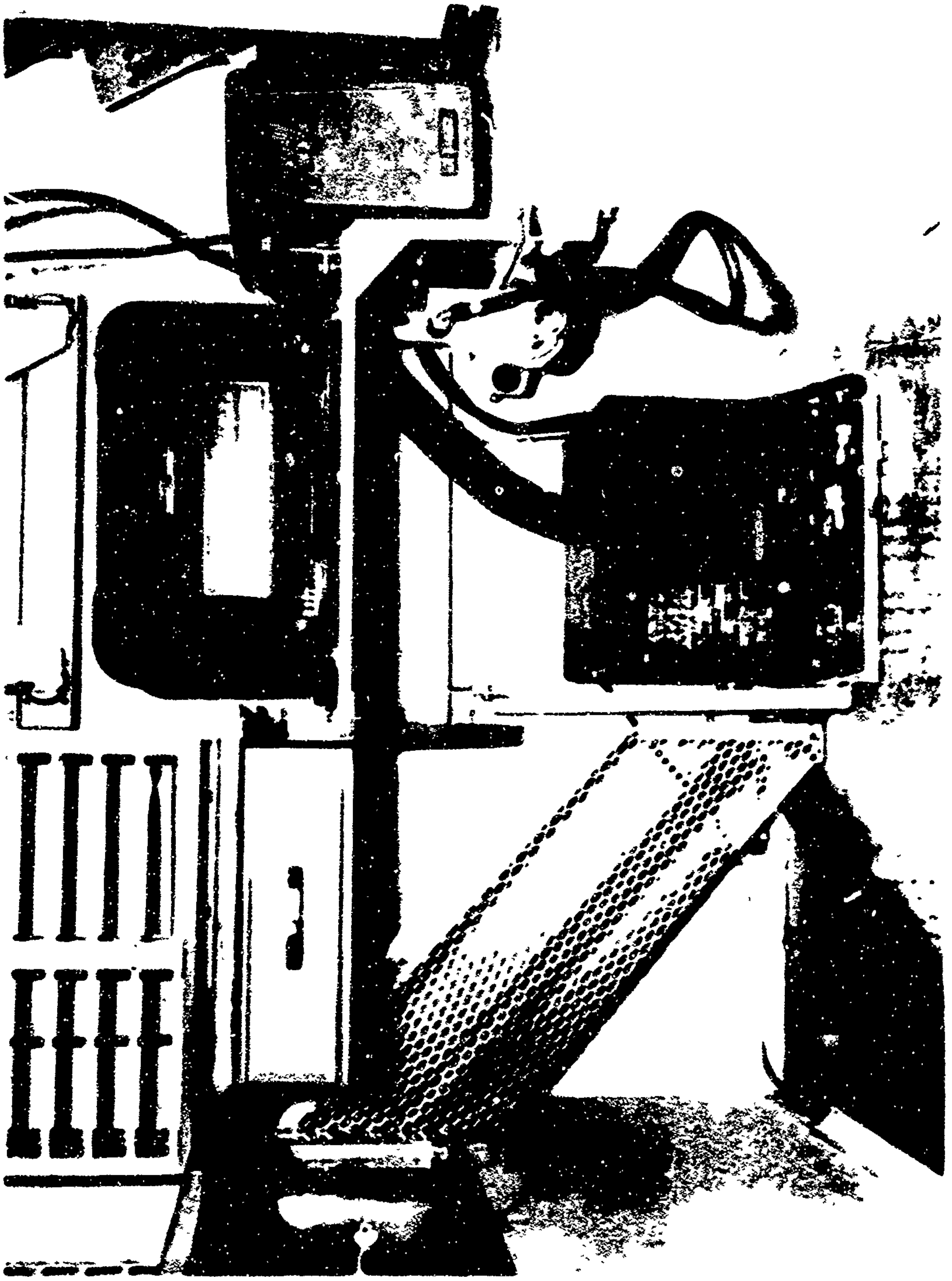


Figure 9-15. Space Heater Mounted on Floor of Shelter

(This photograph is for information only and should not be used as a criterion for the design of similar installations.)

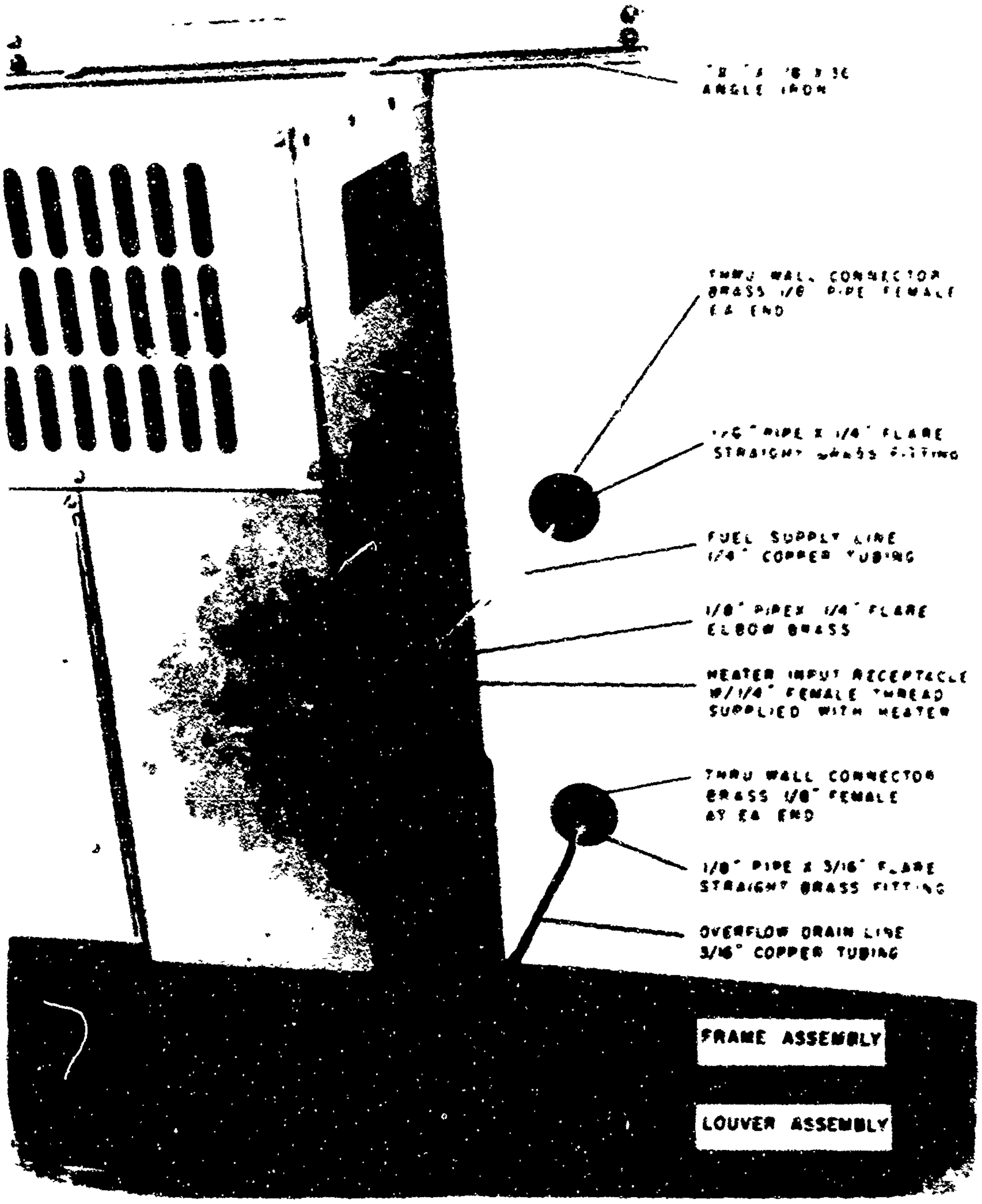


Figure 9-16. Pedestal-mounted, Gasoline-burning Heater

(This photograph is for information only and should not be used as a criterion for the design of similar installations.)

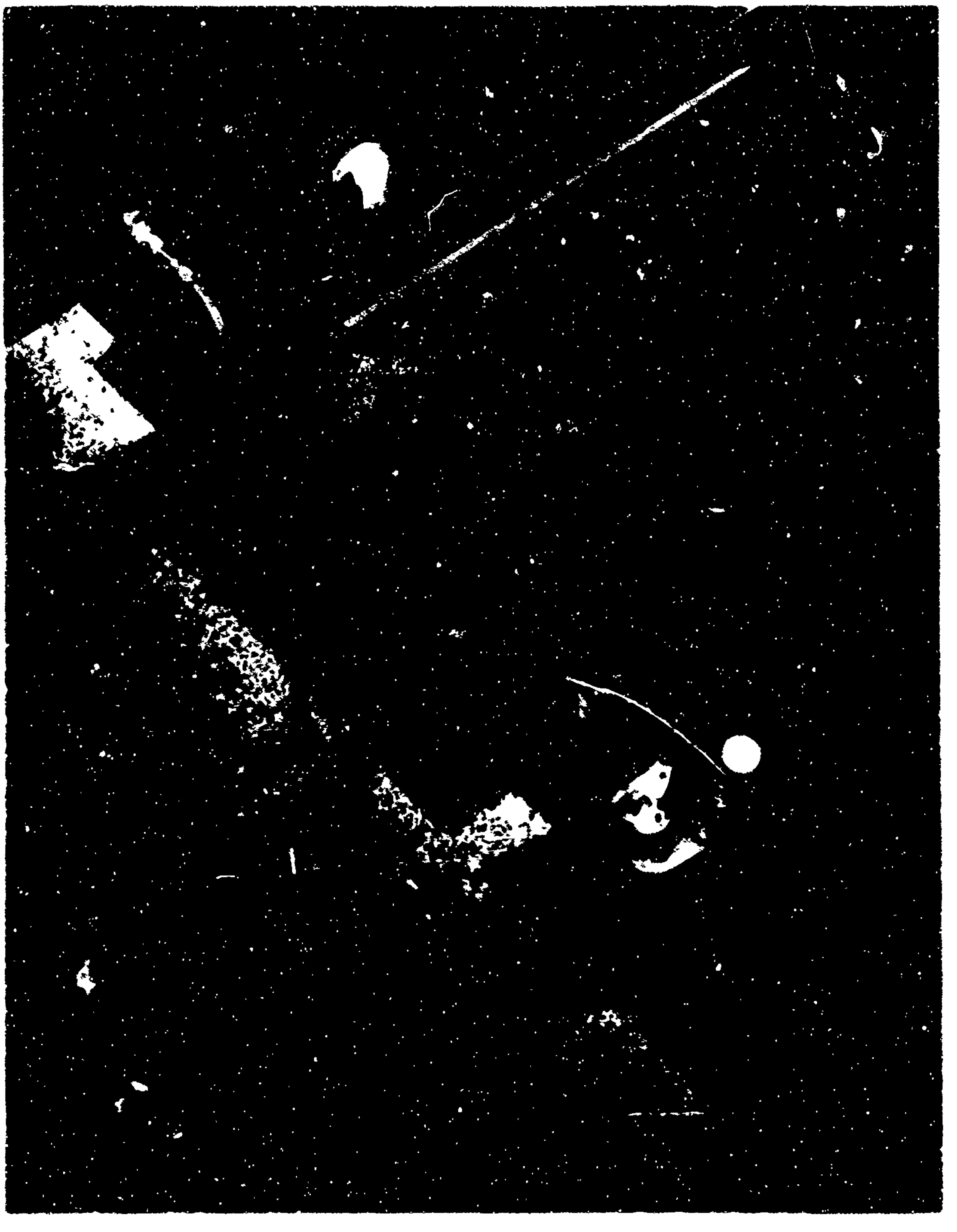


Figure 9-17. Heater Fuel Line With Quick-disconnect Fittings

(This photograph is for information only and should not be used as a criterion for the design of similar installations.)

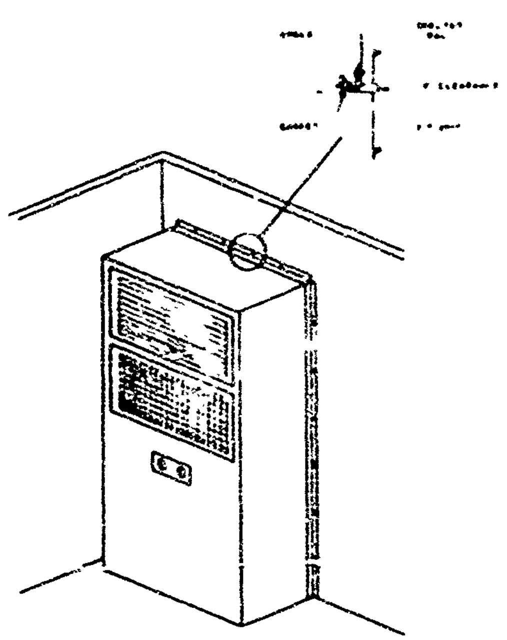


Figure 9-18. Clearance for Vibration Control in Through-the-wall Installation
(Courtesy of Trane Company)
(This drawing does not necessarily represent the latest design techniques and is shown for information only.)

(2) *Heater Exhaust Line.*

The exhaust line of a combustion heater used in a mobile system may consist of a galvanized pipe. It is passed through the wall of the structure and then usually turned vertically upward, so that the exhaust gases are ejected upward into the atmosphere. This helps prevent a high level of contamination in the air near ground level. The outlet end of the pipe should not be near any fresh air intakes or windows and doors. The exhaust line should be as short as possible to keep the back pressure to a minimum. A ventilated air space should surround the exhaust line where it passes through a wall.

It has been found that freezing of moisture which condenses in the exhaust line can restrict flow enough to cause trouble. This can be prevented by installation of a drain line made of copper tubing, as shown in Fig. 9-21. The drain tube should be attached to the lowest point of the exhaust pipe, and it should include a U-trap to provide an air seal.

9-3.3.4 REFRIGERANT PIPING

The installation of air conditioners involves consideration of refrigerant piping only in the case of multiple units designed for interior-exterior installation. Such units are provided with flexible, quick-disconnect refrigerant lines as shown in Fig. 9-10. Provisions must be made for passing these lines through the shelter wall, as indicated in Figs. 9-8 and 9-10. The type of fitting that can be used to connect the exterior hose to the interior hose is shown in Fig. 9-22.

9-3.4 PROVISIONS FOR TRANSPORTATION

When the environmental control units are not in operation, particularly during transportation, all outside air inlets and outlets should be covered for protection. This includes fresh air inlets in the shelter wall, as well as exterior components. Fig. 9-23 illustrates the use of canvas covers and shutters for this purpose.

The telescoping rail type of installation described in par. 9-3.1.5 allows the entire unit to be retracted into the shelter during transit.

9-4 AIR DISTRIBUTION AND CIRCULATION

9-4.1 INTRODUCTION

There are several important factors which must be considered when designing the air circulation and distribution system for environmental control of portable shelters. The quantity, temperature, and humidity of the air supply are the first considerations. Having determined these, the design engineer can then determine the physical characteristics of the environmental control equipment and the size and location of ducts and registers to deliver the air in the desired condition.

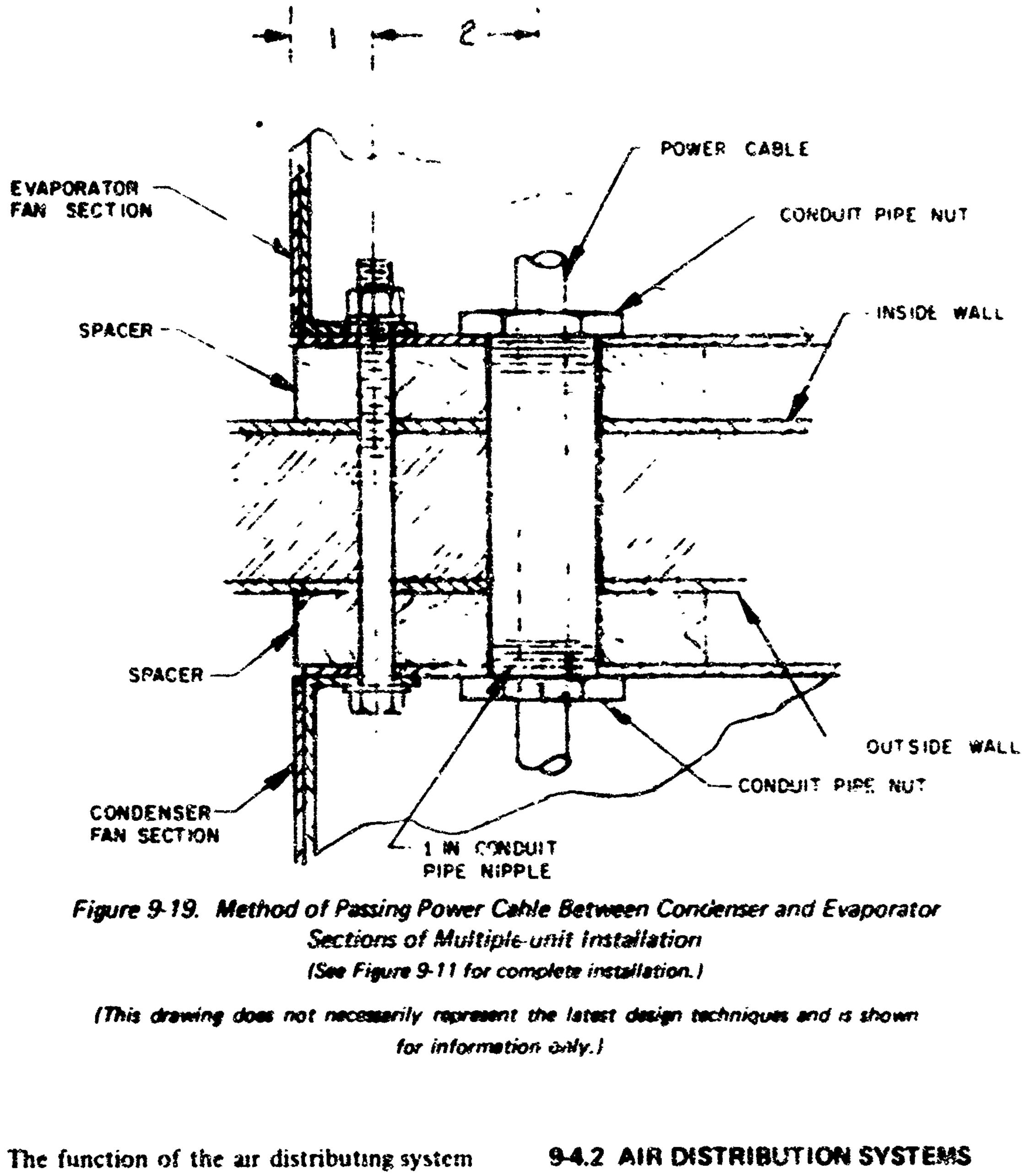


Figure 9-19. Method of Passing Power Cable Between Condenser and Evaporator Sections of Multiple-unit Installation

(See Figure 9-11 for complete installation.)

(This drawing does not necessarily represent the latest design techniques and is shown for information only.)

The function of the air distributing system is to promote uniformity of conditioned air within the space. Conditions at foot level and head level should not differ significantly. There are three factors which contribute to distribution of the air: kinetic energy of the primary air stream, convection resulting from differences in temperature, and movements generated by the continuous introduction and withdrawal of air. These factors are strongly influenced by the design of the supply registers. Their size, location, spacing, the rate of air flow through them, and the direction given to the air are all important factors.

9-4.2 AIR DISTRIBUTION SYSTEMS

Military environmental control units are designed with louvers in the discharge air openings which can be adjusted manually to direct the air in the pattern best fitted to the application. However, it is often necessary to use ductwork to carry the conditioned air to the equipment and spaces where it is needed. When ductwork is used, the louvered grilles on the units do not serve a useful purpose, and they are removed in order to reduce the static pressure loss. If the ductwork is simply an extension of the air discharge opening, the

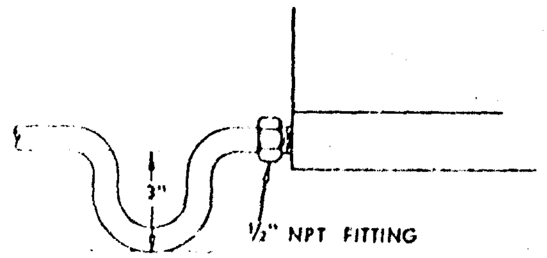


Figure 9-20. Method of Connecting Condensate Drain to Air-conditioning Unit
(Courtesy of Trane Company)

grille removed from the unit may be placed at the end of the duct. Ducts running to fresh air inlets should be connected to environmental control units upstream of the air filter in the unit. The ductwork should include an access door for filter removal.

It is difficult to satisfy the requirements of both heating and cooling operation with a single distribution system. For example, ceiling diffusers are quite acceptable for cooling, but when used for heating it is difficult to

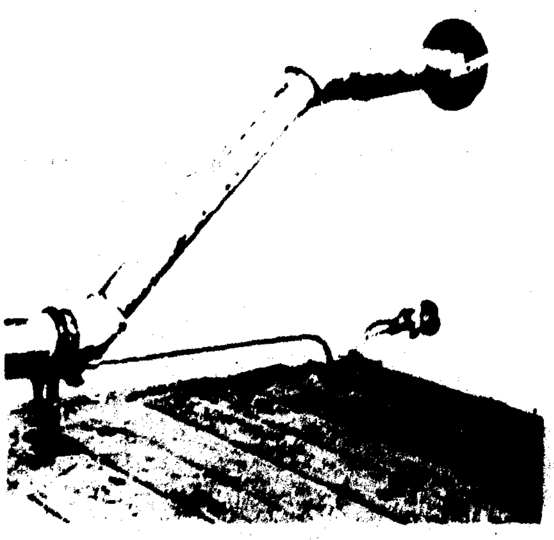


Figure 9-21. Method of Attaching Condensate Drain to Heater Exhaust Line
(This photograph is for information only and should not be used as a criterion for the design of similar installations.)

project the heated air downward with sufficient velocity to mix properly with the cool air at the floor level. For heating conditions it is desirable to have the supply outlets at floor level. As it is seldom practicable to provide separate distribution systems for heating and cooling, it is sometimes necessary to make a compromise which best fits the application.

It is normal practice to take advantage of the fact that only that portion of spaces which may be occupied by personnel need be kept within the acceptable limits of temperature and humidity. That part of the volume above the 6-ft level may be used as a distribution and mixing zone, as indicated in Fig. 9-24. This requires that the primary air be projected with sufficient velocity to entrain room air by induced secondary circulation in amounts up to several times its own volume before it enters the occupied zone. It must be remembered that an air stream projected horizontally will tend to rise if it is warmer than the surrounding air and to fall if it is cooler. It is not easy by projection and entrainment to achieve both good air distribution and adequate mixing throughout the occupied zone. The primary air streams must not be projected directly into the occupied zone. Also, the throw of a register should not be so great that the primary air is "splashed" against a wall without appreciable mixing.

Ceiling plenums may be used for applications requiring a uniform distribution of air over a large area.

The amount of ductwork that may be attached to military air conditioners is limited by the recommended maximum external static pressures. These are about 1 in. of water for units rated up to 11,000 Btu/hr and about 1.5 in. of water for units rated between 18,000 and 60,000 Btu/hr. Because of the relatively small size of the shelters and, therefore, the relatively short runs of ducts, these recommended pressures are not likely to be exceeded unless the application combines use of a remote unit, requiring external ductwork, with a shelter having extensive internal ductwork. Values of total cooling

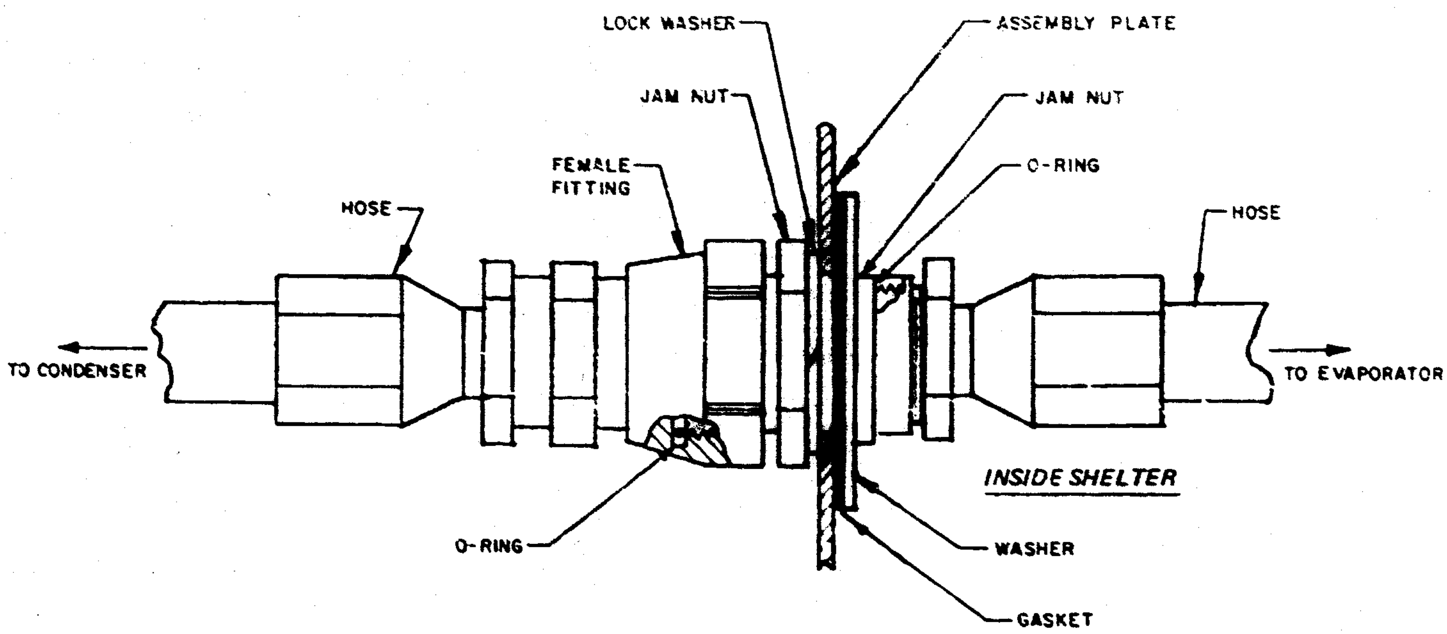
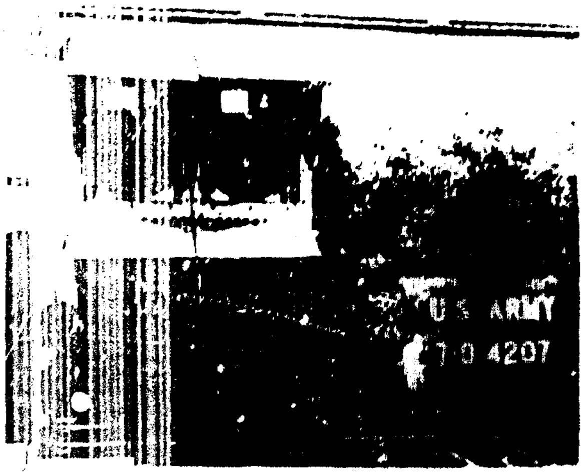
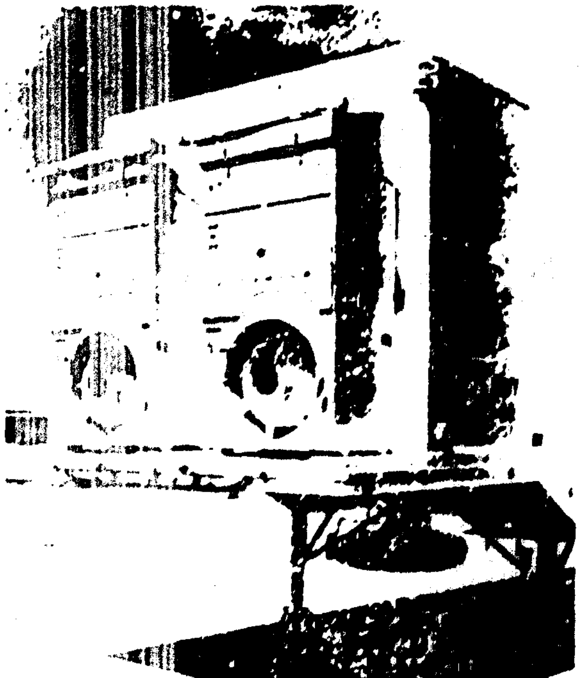


Figure 9-22. Fitting for Connecting Refrigerant Line Through Shelter Wall

(This drawing does not necessarily represent the latest design techniques and is shown for information only.)



(A) Canvas covers for protecting the condenser side of units



(B) Shutters for closing openings through which condensing and ventilating air is drawn

Figure 9-23. Arrangements for Protecting Exterior Openings in the Environmental Control System During Transit[2]

(Courtesy of Trane Company)

capacity are usually based on free-discharge air flow. If the air flow rate is reduced by static pressure losses in ductwork, the cooling capacity will decrease correspondingly.

9-4.3 GENERAL RULES OF VENTILATION

The following are some general ventilation rules[7]:

(1) The greatest volume rate of air flow per unit area of total opening is obtained by using inlet and outlet openings of nearly equal area.

(2) Short circuits of air flow between openings on two sides of a high level may clear the air at that level without producing appreciable ventilation at other levels.

(3) To enhance the generation of convection currents by temperature differences, the vertical distance between inlet and outlet should be as great as possible.

9-4.4 METHODS OF AVOIDING OBJECTIONABLY HIGH AIR VELOCITIES

In small enclosures with large cooling loads it is possible that the air flow rate required will create objectionably high velocities in personnel spaces. In order to control the environment properly, the air within the shelter must be circulated or exchanged with a minimum of discomfort or distraction to the occupants.

There are two problems involved in the use of unnecessarily high air velocities: the noise generated in the duct system increases with increase in air velocities, and the occupants of the shelter may be made very uncomfortable by drafts, especially when the cooling cycle is being used. An air velocity of 35 ft/min in contact with personnel has been considered acceptable[8].

Excessive air velocities usually have two basic causes: undersized ducts or improper outlet register design. In systems with undersized ducts, air velocities must be kept high to maintain the mass-flow rate of air required for proper operation during the cooling cycle.

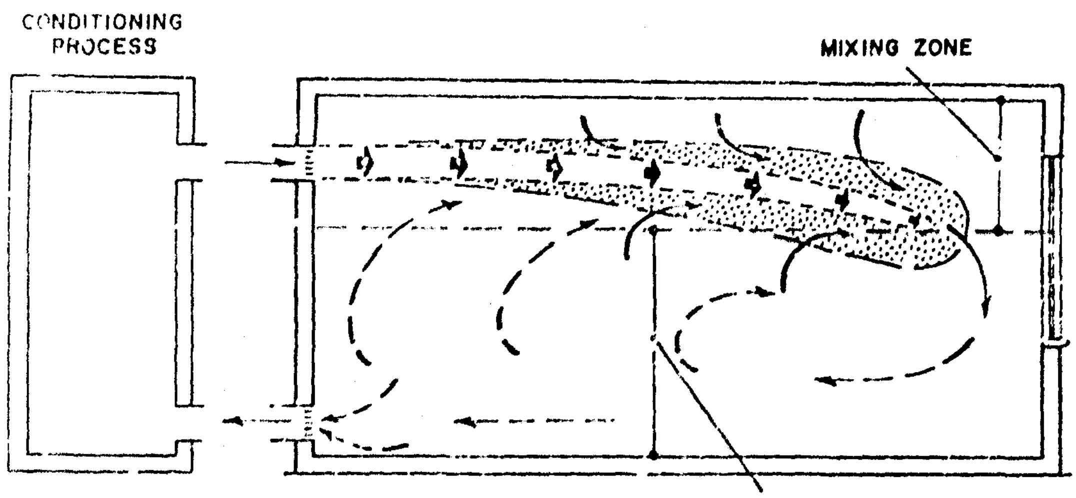


Figure 9-24. Basic Air Distribution Problem[6]

Uncomfortable drafts and excessive noise result. A system delivering 10% more than its rated flow will have a noise increase of 60%[9]. Improper register design will usually be caused by attempts to increase the throw of the entering air stream to compensate for use of too few registers in the system. The result is most noticeable during cooling cycles as evidenced by improper mixing of the entering air stream and drafts due to impingement on walls or equipment. Some of these problems can be avoided by proper selection of the size and location of the air outlets.

Another way to avoid objectionably high velocities is to reduce the air flow requirements by reducing the sensible heat load. Thermal insulation may be improved. Air used to cool apparatus can be isolated from the personnel space and exhausted to the outside.

9-4.5 HEATING SYSTEMS

9-4.5.1 AIR DISTRIBUTION WITH AND WITHOUT DUCTWORK

Heated air should be discharged at a low level, so that its natural tendency to rise will result in low floor-to-ceiling temperature differences. In the majority of heater installations in shelters and trucks the space to be controlled is small enough so that ducts are not needed to distribute the heated air. Even in the larger shelters and trucks, floor- and pedestal-mounted installations – similar to those shown in Figs. 9-11, 9-13, 9-14, and 9-16 – can be used. In semitrailers, vertical or horizontal floor-level ducts, similar to those shown in Figs. 9-2 and 9-3, can be used.

Overhead duct systems are undesirable for the distribution of heated air because they are likely to have poor air distribution to the floor level, resulting in excessive air stratification. These detrimental effects can be corrected to some extent by increasing the air discharge velocity and directing it downward, provided the temperature differential between supply air and room air is not excessive. See pars. 9-4.4 and 9-5.5.

9-4.5.2 CONDITIONS IN POLAR REGIONS

Conditioning air in inhabited structures is probably most difficult in polar regions. Added to the extremely low temperatures, low absolute humidity and the general use of structures of lightweight construction contribute to the difficulties. In addition to supplying enough heat to raise the temperature to the level required, it is necessary to maintain sufficient air flow to prevent stratification and stagnation of air and to supply

the proper amount of moisture to raise the relative humidity of the comfort level without an excess of frost and condensation on cool surfaces.

Stratification can be avoided with air distribution systems, such as a floor plenum system, which discharge warm air at a low level. The natural convection currents generated by the upward movement of the warm air and downward movement of cool air tend to mix the air. When warm air is discharged from overhead locations, it is difficult to attain uniform heat distribution. Substantial downward components of ejection velocity are needed in this case to avoid stratification but, in any case, floor areas will be relatively cool.

Tests[10] on heating systems designed for polar use showed that condensation and frosting on cool surfaces may become a problem when humidifiers are used to raise the moisture content of the air. For example, it was found that frost formation made it difficult to operate the regulating damper in the fresh-air intake duct. The experimenters suggested that the problem be solved by use of an intake duct of sealed, double sheet-metal construction with insulation between the two metal casings.

The following are general steps which can be taken to minimize the condensation and frosting problem:

(1) Seal joints and cracks to prevent seepage of cold air into the conditioned space and the consequent cooling of surfaces over which the air flows.

(2) If possible, add insulation between the more critical surfaces and the heat sinks.

(3) Use no more humidification than is necessary to produce the required conditions.

9-5. DUCT DESIGN

9-5.1 GENERAL RULES OF DUCT DESIGN

In most cases, the duct system for a shelter is designed to provide both heating and cooling functions. The usual practice is to design the ducts so that they provide optimum air supply velocities during cooling, when the rate of air flow and air density are highest.

For most applications to mobile systems, the fan available in the environmental control unit will meet the air flow requirements. In cases where it is necessary to provide auxiliary fans, Ref. 11 and Chapter 4 of Ref. 12 may be consulted.

The general rules which should be followed in the design of ducts, given in Chapter 3 of Ref. 12, are:

"1. The air should be conveyed as directly as possible at the permissible velocities to obtain the desired results with minimum noise and greatest economy of power, material, and space.

"2. Sudden changes in the direction or velocity of the air should be avoided. When sudden changes are necessary at bends, turning vanes should be used to minimize the pressure loss.

"3. Where the greatest air carrying capacity per square foot of sheet metal is desired, rectangular ducts should be made as nearly square as possible. Aspect ratios (ratio of width to depth) greater than 8 to 1 should be avoided. Where possible, a ratio of 4 to 1 or less should be maintained.

"4. Ducts should be constructed of smooth material, such as steel or aluminum sheet metal. For ducts made from other materials, proper allowance for the change in roughness should be made[13].

"5. . . . it should be recognized that, in actual installations, [flow] resistances may vary considerably from the calculated values because of variation in the smoothness of materials, types of joints used, and the ability of workmen to

fabricate the system in accordance with the design. Fans and motors should, therefore, be selected to provide at least a slight factor of safety, and dampers should be installed in each branch outlet for balancing the system.

"6. Avoid obstructing ducts with piping, conduits, or structural members. Unavoidable duct obstructions must be streamlined with an *easement* or a *tear-drop*, the length of which should be at least three times the thickness of the tear-drop."

Some of these rules are illustrated in Fig. 9-25.

9-5.2 DESIGN VELOCITIES

The velocities listed in Table 9-1, which are reported[12] to have given satisfactory results in conventional systems, may provide a guide for selecting the velocity of air in ducts. Since pressure losses increase approximately as the square of the velocity and fan noise generation increases with static pressure, velocities

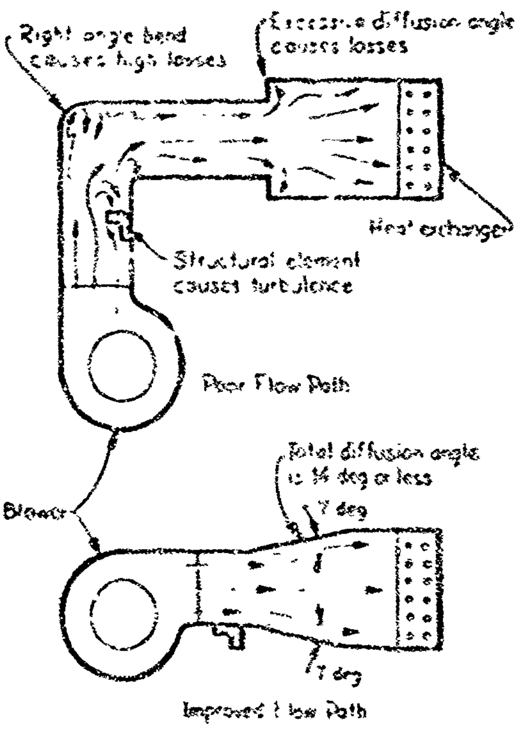


Figure 9-25. Illustration of Poor and Good Duct Design[8]

TABLE 9-1

RECOMMENDED AND MAXIMUM DUCT VELOCITIES FOR CONVENTIONAL SYSTEMS

(Adapted from Ref. 12, Chapter 3)

Designation	Residences	Industrial Buildings
	Recommended Velocities, ft/min	
Outdoor Air Intakes[a]	500	500
Filters[a]	250	350
Fan Outlets	1000-1600	1600-2400
Main Ducts	700-900	1200-1800
Branch Ducts	500	800-1000
Branch Risers	500	800
	Maximum Velocities, ft/min	
Outdoor Air Intakes[a]	800	1200
Filters[a]	300	350
Fan Outlets	1700	1700-2800
Main Ducts	800-1200	1300-2200
Branch Ducts	700-1000	1000-1800
Branch Risers	650-800	1000-1600

[a]These velocities are for total face area, not the net free area; other velocities in table are for net free area.

should be kept low for quiet and efficient operation. On the other hand, the velocities within the ducts should not be too low because the duct size increases as the velocity is decreased. Adequate performance will usually result if supply duct velocities of 600 to 700 ft/min are used.

9-5.3 DESIGN PROCEDURE

The general procedures for duct design, adapted from Ref. 12, are

(1) Study the plan of the structure and arrange the positions of the supply outlets to provide proper distribution of air.

(2) Select outlet sizes.

(3) Draw a sketch of the most convenient duct system connecting the supply outlets

and return intakes with the environmental control units.

(4) Calculate the sizes of the main duct and all branch ducts.

(5) Determine the total (net) pressure loss through the entire duct system, including the return system if one is used.

Of the three duct design methods[12] — velocity reduction, equal-friction, and static-regain — the velocity-reduction method is the one best suited for the small duct systems used in mobile military structures. As the term indicates, the duct sizes are chosen so that there are progressively lower velocities at each branch duct as one moves downstream in the main duct. On the assumption that the main duct is no larger than the discharge opening of the environmental control unit, the lowest velocity at the entrance to the main duct can be estimated from the known air flow rate and the size of the discharge opening. If the cross-sectional area of the main duct is made smaller than the area of the discharge opening in the unit, the entrance velocity will be increased. The velocities in the main duct at each branch point are chosen arbitrarily, except that they are chosen progressively smaller as one moves away from the entrance. Knowing the volume rate of air flow through each portion of the duct system enables one to compute the areas of the ducts from the chosen velocities. The graph in Fig. 9-26 may be used to obtain duct diameters, and Table 9-2 may be used to obtain equivalent rectangular sizes. The pressure drop in the air path having the greatest resistance should be calculated. If the pressure drop exceeds the capability of the fan in the environmental control unit, it is necessary either to increase duct sizes to lower the pressure loss or to provide auxiliary fans.

Resistance to flow in the duct system is developed by both friction and turbulence. For a straight smooth duct the resistance varies inversely as the fifth power of the duct diameter, and it is proportional to the length. Tables and charts are available, such as Fig. 9-26, which provides values of resistance for straight ducts in terms of pressure loss per unit length for each specific duct cross-sectional configuration*. Charts are also available which permit determination of the losses that occur in most of the common duct fittings and shapes[12].

If there is a return duct system, it is sized in the same way that the supply ducts are sized — starting with the lowest velocities at the return intakes and increasing them progressively as the environmental control unit is approached.

Dampers should be provided to permit balancing the system for the conditions actually encountered during use.

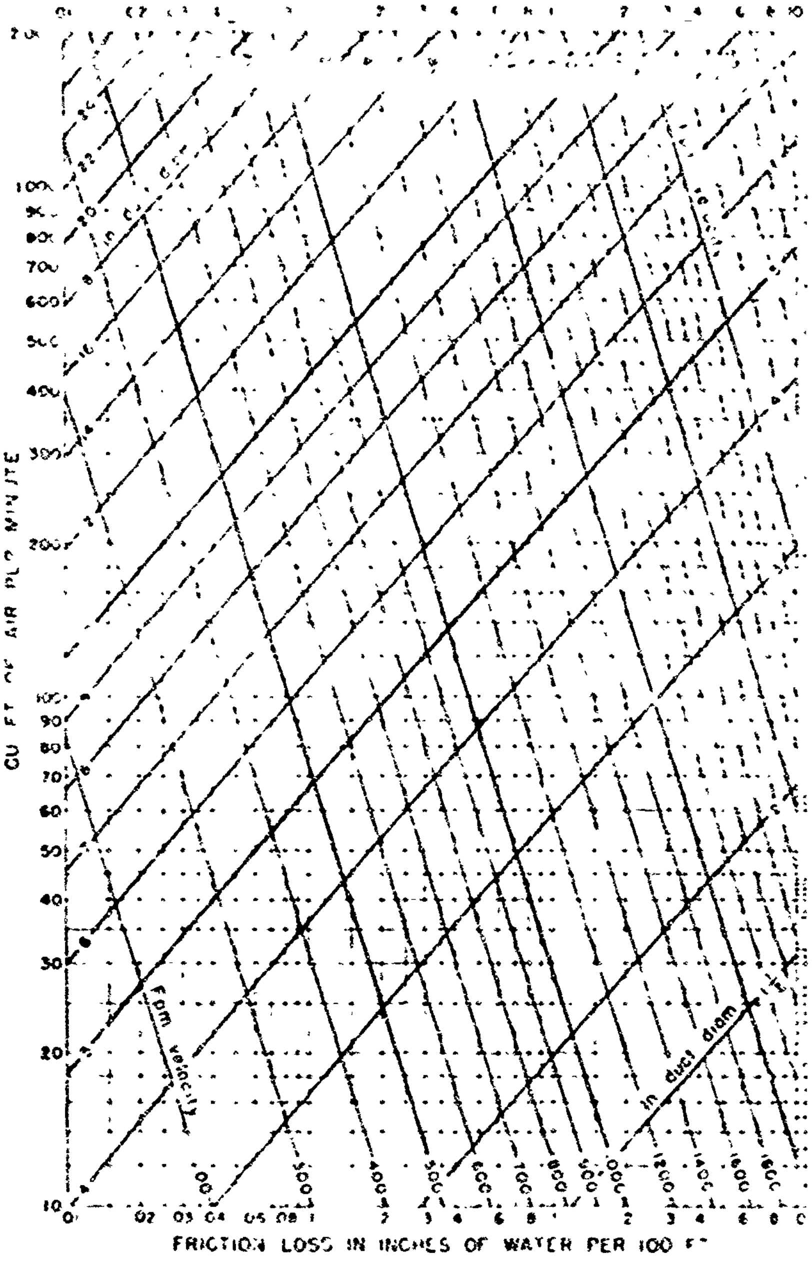
A refinement of the described procedure is to design the main duct first and to determine the pressure head available at each branch point; then each branch is designed to have a pressure loss equal to, or somewhat less than, the available pressure head.

9-5.4 DUCT FABRICATION

Ducts used in the environmental control systems of transportable military structures fit into the *low pressure* classification, which includes those with mean air velocities less than 2,000 ft/min and static pressures less than 2 in. of water[12]. Table 9-3 shows recommendations for the construction of rectangular ducts. To conserve space, round ducts are rarely used inside the structures under consideration. All duct construction details should be in accordance with Section I of the *Duct Manual and Sheet Metal Construction for Ventilation and Air Conditioning Systems*[18].

In the interest of maintaining uniform velocities — accompanied by decreased turbulence, lower resistance, and less noise — elbows should have long radii and shape changes should be as gradual as possible. To

*See also pages 50, 51, 60, and 61 of Ref. 15, Ch. 2 of Ref. 16, and page 284 of Ref. 17.



(Based on Standard Air of 0.075 lb per cu ft density flowing through average clean round, galvanized metal ducts having approximately 40 joints per 100 ft. Errors of less than 3% are incurred in using this figure for air temperatures as low as 50° F or as high as 90° F. The usual variations in air pressure and humidity can be disregarded.) Caution: Do not extrapolate below chart.

Figure 9-26. Friction of Air in Straight Ducts for Volumes of 10 to 2,000 cfm (From Ref. 12, Chapter 3.)

TABLE 9-2

CIRCULAR EQUIVALENTS OF RECTANGULAR DUCTS FOR EQUAL FRICTION AND CAPACITY[1,2]

Dimensions in Inches

Side Rectangular Duct	40	45	50	55	60	65	70	75	80	90	100	110	120	130	140	150	160
3	3.9	4.0	4.2	4.4	4.6	4.8	4.9	5.1	5.2	5.5	5.7	6.0	6.2	6.4	6.6	6.8	7.0
3.5	4.1	4.3	4.6	4.8	5.0	5.2	5.3	5.5	5.7	6.0	6.3	6.5	6.8	7.0	7.2	7.4	7.6
4	4.4	4.6	4.9	5.1	5.3	5.5	5.7	5.9	6.1	6.4	6.8	7.1	7.4	7.6	7.8	[illegible]	8.3
4.5	4.6	4.9	5.2	5.4	5.6	5.9	6.1	6.3	6.5	6.9	7.2	7.5	7.8	8.1	8.4	8.6	8.9
5.0	4.9	5.2	5.5	5.7	6.0	6.2	6.4	6.7	6.9	7.3	7.6	8.0	8.3	8.6	8.9	[illegible]	9.5
5.5	5.1	5.4	5.7	6.0	6.3	6.5	6.8	7.0	7.2	7.6	8.0	8.4	8.7	9.0	[illegible]	[illegible]	9.8

Side Rectangular Duct	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	22	24	26	28	30	Side Rectangular Duct
6	6.6																				6
7	7.1	7.7																			7
8	7.5	8.2	8.8																		8
9	8.0	8.6	9.3	9.9																	9
10	8.4	9.1	9.8	10.4	10.9																10
11	8.8	9.5	10.2	10.8	11.4	12.0															11
12	9.1	9.9	10.7	11.3	11.9	12.5	13.1														12
13	9.5	10.3	11.1	11.8	12.4	13.0	13.6	14.2													13
14	9.8	10.7	11.5	12.2	12.9	13.5	14.2	14.7	15.3												14
15	10.1	11.0	11.8	12.6	13.3	14.0	14.6	15.3	15.8	16.4											15
16	10.4	11.4	12.2	13.0	13.7	14.4	15.1	15.7	16.3	16.9	17.5										16
17	10.7	11.7	12.5	13.4	14.1	14.9	15.5	16.1	16.8	17.4	18.0	18.6									17
18	11.0	11.9	12.9	13.7	14.5	15.3	16.0	16.6	17.3	17.9	18.5	19.1	19.7								18
19	11.2	12.2	13.2	14.1	14.9	15.6	16.4	17.1	17.8	18.4	19.0	19.6	20.2	20.8							19
20	11.5	12.5	13.5	14.4	15.2	15.9	16.8	17.5	18.2	18.8	19.5	20.1	20.7	21.3	21.9						20
22	12.0	13.1	14.1	15.0	15.9	16.7	17.6	18.3	19.1	19.7	20.4	21.0	21.7	22.3	22.9	24.1					22
24	12.4	13.6	14.6	15.6	16.6	17.5	18.3	19.1	19.8	20.6	21.3	21.9	22.6	23.2	23.9	25.1	26.2				24
26	12.8	14.1	15.2	16.2	17.2	18.1	19.0	19.8	20.6	21.4	22.1	22.8	23.5	24.1	24.8	26.1	27.2	28.4			26
28	13.2	14.5	15.6	16.7	17.7	18.7	19.6	20.5	21.3	22.1	22.9	23.6	24.4	25.0	25.7	27.1	28.2	29.5	30.6		28
30	13.6	14.9	16.1	17.2	18.3	19.3	20.2	21.1	22.0	22.9	23.7	24.4	25.2	25.9	26.7	28.0	29.3	30.5	31.6	[illegible]	30
32	14.0	15.3	16.5	17.7	18.8	19.8	20.8	21.8	22.7	23.6	24.4	25.2	26.0	26.7	27.5	28.9	30.1	31.4	32.6	[illegible]	32
34	14.4	15.7	17.0	18.2	19.3	20.4	21.4	22.4	23.3	24.2	25.1	25.9	26.7	27.5	28.3	29.7	31.0	32.3	[illegible]	[illegible]	34
36	14.7	16.1	17.4	18.6	19.8	20.9	21.9	23.0	23.9	24.8	25.8	26.6	27.4	28.3	29.0	30.5	31.6	33.0	[illegible]	[illegible]	36
38	15.0	16.4	17.8	19.0	20.3	21.4	22.5	23.5	24.5	25.4	26.4	27.3	28.1	29.0	29.8	31.4	32.8	34.2	[illegible]	[illegible]	38
40	15.3	16.8	18.2	19.4	20.7	21.9	23.0	24.0	25.1	26.0	27.0	27.9	28.8	29.7	30.5	32.1	33.6	35.1	36.4	[illegible]	40
42	15.6	17.1	18.5	19.8	21.1	22.3	23.4	24.5	25.6	26.6	27.6	28.5	29.4	30.4	31.2	32.8	34.4	35.9	37.3	38.6	42
44	15.9	17.5	18.9	20.2	21.5	22.7	23.9	25.0	26.1	27.2	28.2	29.1	30.0	31.0	31.9	33.5	35.2	[illegible]	38.1	39.5	44
46	16.2	17.8	19.2	20.6	21.9	23.2	24.3	25.5	26.7	27.7	28.7	29.7	30.6	31.6	32.5	34.2	35.9	37.4	38.9	40.3	46
48	16.5	18.1	19.6	20.9	22.3	23.6	24.8	26.0	27.2	28.2	29.2	30.2	31.2	32.2	33.1	34.9	36.6	38.2	39.7	41.2	48
50	16.8	18.4	19.9	21.3	22.7	24.0	25.2	26.4	27.6	28.7	29.8	30.8	31.8	32.8	33.7	35.5	37.3	38.9	[illegible]	42.0	50
52	17.0	18.7	20.2	21.6	23.1	24.4	25.6	26.8	28.1	29.2	30.3	31.4	32.4	33.4	34.3	36.2	38.0	39.6	41.2	42.8	52
54	17.3	19.0	20.5	22.0	23.4	24.8	26.1	27.3	28.5	29.7	30.8	31.9	32.9	[illegible]	34.9	36.8	38.7	40.3	42.0	43.6	54
56	17.6	19.3	20.9	22.4	23.8	25.2	26.5	27.7	28.9	30.1	31.2	32.4	33.4	34.5	[illegible]	37.4	39.3	41.0	[illegible]	44.3	56
58	17.8	19.5	21.1	22.7	24.2	25.5	26.9	28.2	29.3	30.5	31.7	32.9	33.9	35.0	36.0	38.0	39.8	41.7	43.4	[illegible]	58
60	18.1	19.8	21.4	23.0	24.5	25.8	27.3	28.7	29.8	31.0	32.2	33.4	34.5	35.5	36.5	38.6	40.4	42.3	44.0	45.8	60
62	18.3	20.1	21.7	23.3	24.8	26.2	27.6	29.0	30.2	31.4	[illegible]	33.8	35.0	36.0	37.1	39.2	41.0	42.9	[illegible]	46.5	62
64	18.6	20.3	22.0	23.6	25.2	26.5	27.9	29.3	30.6	31.8	33.1	[illegible]	35.5	36.5	37.6	[illegible]	[illegible]	[illegible]	45.4	47.2	64
66	18.8	20.6	22.3	23.9	25.5	26.9	28.3	29.7	31.0	32.2	33.5	34.7	35.9	37.0	[illegible]	[illegible]	42.2	44.1	46.0	[illegible]	66
68	19.0	20.8	22.5	24.2	25.8	27.3	28.7	30.1	31.4	32.6	33.9	35.1	[illegible]	37.5	[illegible]	[illegible]	[illegible]	[illegible]	46.6	[illegible]	68
70	19.2	21	22.8	24.5	26.1	27.6	29.1	30.4	31.8	33.1	34.3	35.6	36.8	37.9	39.1	41.3	43.3	45.3	47.2	49.0	70
72															39.6	41.9	43.9	45.9	[illegible]	[illegible]	72
74															40.0	42.3	44.4	46.4	48.4	50.3	74
76															40.5	42.8	44.9	47.0	[illegible]	50.9	76
78															40.9	43.3	45.4	47.5	49.5	[illegible]	78
80															41.3	43.8	46.0	48.0	50.1	52.0	80
82															41.8	44.2	46.4	48.6	50.6	52.6	82
84															42.2	44.6	46.9	49.2	51.1	53.2	84
86															42.6	45.0	47.4	49.6	[illegible]	[illegible]	86
88															43.0	45.4	47.9	50.1	[illegible]	54.3	88
90															43.4	45.9	48.3	50.6	[illegible]	[illegible]	90
92															43.8	46.3	48.7	51.1	53.4	55.4	92
96															44.6	47.2	49.5	52.0	[illegible]	[illegible]	96

Equation for Circular Equivalent of a Rectangular Duct[4]

$$d_e = 1.30\,\frac{(ab)^{0.625}}{(a+b)^{0.250}} = 1.30\,\sqrt[8]{\frac{(ab)^5}{(a+b)^2}}$$

where

a = length of one side of rectangular duct, in

b = length of adjacent side of rectangular duct, in

d_e = circular equivalent of a rectangular duct for equal friction and capacity, in

TABLE 9-3

RECOMMENDED CONSTRUCTION FOR RECTANGULAR LOW PRESSURE DUCTS

Dimension of Longest Side, Inches	Sheet Metal Gage (All Four Sides)[a,b]: Steel Gage	Aluminum Alloy[b] Thickness, In.	Copper Oz Per Sq Ft	Minimum Reinforcing Angle Size and Maximum Longitudinal Spacing Between Transverse Joints and or Intermediate Reinforcing[d]	Max. H, In.	Transverse Reinforcing[c], All Joints[e]: Drive Slip / Plain S Slip — Recommended Gage	Hemmed S Slip — Recommended Gage	Alternate Bar Slip — Recommended Gage	Reinforced Bar Slip — Recommended Gage	Bar Slip / Angle Slip — Recommended Gage	Bar Slip / Angle Slip — Reinforced Angle Size	Standing Seam / Angle Reinforced Standing Seam — Reinforced Angle Size	Pocket Lock / Angle Reinforced Pocket Lock — Recommended Gage	Pocket Lock / Angle Reinforced Pocket Lock — Reinforced Angle Size	Gasket or Sealer, Companion Angles — Reinforced Angle Size
Up thru 12	26	0.020	16	None Required	1	26	26	24	24	24	Not Required	Not Required	24	Not Required	—
13-18	24	0.025	24	None Required	1	24	24	24	24	24	Not Required	Not Required	24	Not Required	—
19-30	24	0.025	24	1 × 1 × 1/8 @ 60 in.	1	—	24	24	24	24	Not Required	Not Required	22	Not Required	—
31-42	22	0.032	32	1 × 1 × 1/8 @ 60 in.	1	—	—	22	22	22	Not Required	Not Required	22	Not Required	—
43-54[f]	22	0.032	32	1½ × 1½ × 1/8 @ 60 in.[f]	1½	—	—	22	22	22	1 × 1 × 1/8	Not Required	22	Not Required	—
55-60	20	0.040	36	1½ × 1½ × 1/8 @ 60 in.	1½	—	—	22	22	22	1½ × 1½ × 1/8	Not Required	22	Not Required	—
61-84	20	0.040	36	1½ × 1½ × 1/8 @ 30 in.	1½	—	—	—	22	22	1½ × 1½ × 1/8	1½ × 1½ × 1/8	22	1½ × 1½ × 1/8	—
85-96	18	0.050	48	1½ × 1½ × 3/16 @ 30 in.	1½	—	—	—	—	22	1½ × 1½ × 3/16	1½ × 1½ × 3/16	22	1½ × 1½ × 3/16	1½ × 1½ × 3/16
97-120	18	0.050	48	2 × 2 × 1/8 @ 30 in.	2	—	—	—	—	22	2 × 2 × 1/8	2 × 2 × 1/8	22	2 × 2 × 1/8	2 × 2 × 1/8
Over 120	18	0.050	48	2 × 2 × 1/4 @ 30 in.	2	—	—	—	—	22	2 × 2 × 1/4	2 × 2 × 1/4	22	2 × 2 × 1/4	2 × 2 × 1/4

a Flat areas of duct over 18 in. wide shall be cross broken [illegible]
b Suitable aluminum alloys are [illegible]
c Transverse reinforcing [illegible]
d There is no restriction on the length of [illegible]
e [illegible]
f [illegible]
g [illegible]
h [illegible]
i Pocket locks [illegible]

Copyrighted by ASHRAE. Reprinted by permission from ASHRAE Guide and Data Book 1969.

reduce the transmission of vibrations and noise, flexible connections should be used where the ducts are attached to the environmental control units. This is especially important if the unit is mounted on vibration isolators.

Figs. 9-27 through 9-35 illustrate the application of air distribution systems to mobile military structures.

9-5.5 SUPPLY OUTLETS

The duct systems used in shelters may have supply outlets in the floor, in the lower sidewall, in the upper sidewall, or in the ceiling. In using floor registers for heating, the supply air should have sufficient velocity to spread over the room and reach the wall where most of the heat loss occurs. Low sidewall outlets should provide a horizontal spread of air over the floor area for heating and be adjustable to direct air to the upper levels of the shelter space for cooling. Ceiling and upper sidewall registers are especially effective in cooling applications, however, where used for heating, maximum effectiveness of this system requires high air supply velocities, with a temperature differential between supply air and room air less than 25°F. The general characteristics of outlet registers in different placements are indicated in Table 9-4.

9-5.6 DUCTS FOR REMOTE UNITS

Ductwork is also needed when an environmental control unit is mounted remote from the shelter. Conversion of the units for flexible duct application requires supply and return air plenums, a supply grille, and an opening for the return air. A skid-mounted unit is shown with these components in Fig. 9-36. The figure also shows the containers in which the ducts are stored during transit.

Round flexible ducts are used to connect remote units with the shelter. The sections of flexible duct should be kept as straight and as short as possible. Flexible duct connections can be made most easily if they are provided with mating flanges which can be clamped together with locking pins, without the use of tools (see Fig. 9-37). Some flexible ducts are attached at their ends by sliding them over a flange and then tightening a metal ring which clamps the duct to the flange. (See Fig. 9-38.) This is not as convenient as the flange-and-locking-pin arrangement, but it may be acceptable if the ducts are not to be connected and disconnected often.

9-5.7 SELECTION OF DUCT MATERIAL

In the selection of materials for fabricated ducts, or materials for use as ducts or duct fittings the designer should consider several factors in regard to the properties of the materials:

(1) Flame propagation and smoke producing characteristics

(2) Odor emission likely at operating temperatures

(3) Toxic gas emission

(4) Resistance to deformation or deterioration at operating temperatures

(5) Air tightness

(6) Resistance to vermin infestation

(7) Moisture absorption and transmission

(8) Resistance to mold growth

(9) Resistance to corrosion, erosion, and delamination.

9-6 CONTROLS

9-6.1 CONTROL PANEL

The control panel on environmental control units can be removed for remote mounting. This makes it possible to locate the panel where the switches can be operated conveniently. The opening left by removal of the control panel should be closed with a blank

Figure 9-27. Portion of Heater Discharge Duct in Semi-trailer

(This photograph is for information only and should not be used as a criterion for the design of similar installations.)

TABLE 9-4

GENERAL CHARACTERISTICS OF OUTLETS

Group	Outlet Type	Outlet Flow Pattern	Most Effective Application	Preferred Location	Size Determined by
1	Ceiling and high side-wall	Horizontal	Cooling	Not Critical	Major Application heating or cooling
2	Floor registers and low sidewall	Vertical, nonspreading	Cooling and Heating	Not Critical	Maximum acceptable heating temperature differential
3	Floor registers and low sidewall	Vertical, spreading	Heating and Cooling	Along perimeter	Minimum supply velocity differs with type and acceptable temperature differential
4	Low sidewall	Horizontal	Heating only	Long outlet perimeter, short outlet not critical	Maximum supply velocity should be less than 300 fpm

Copyrighted by ASHRAE Reprinted by permission from ASHRAE Guide and Data Book 1970

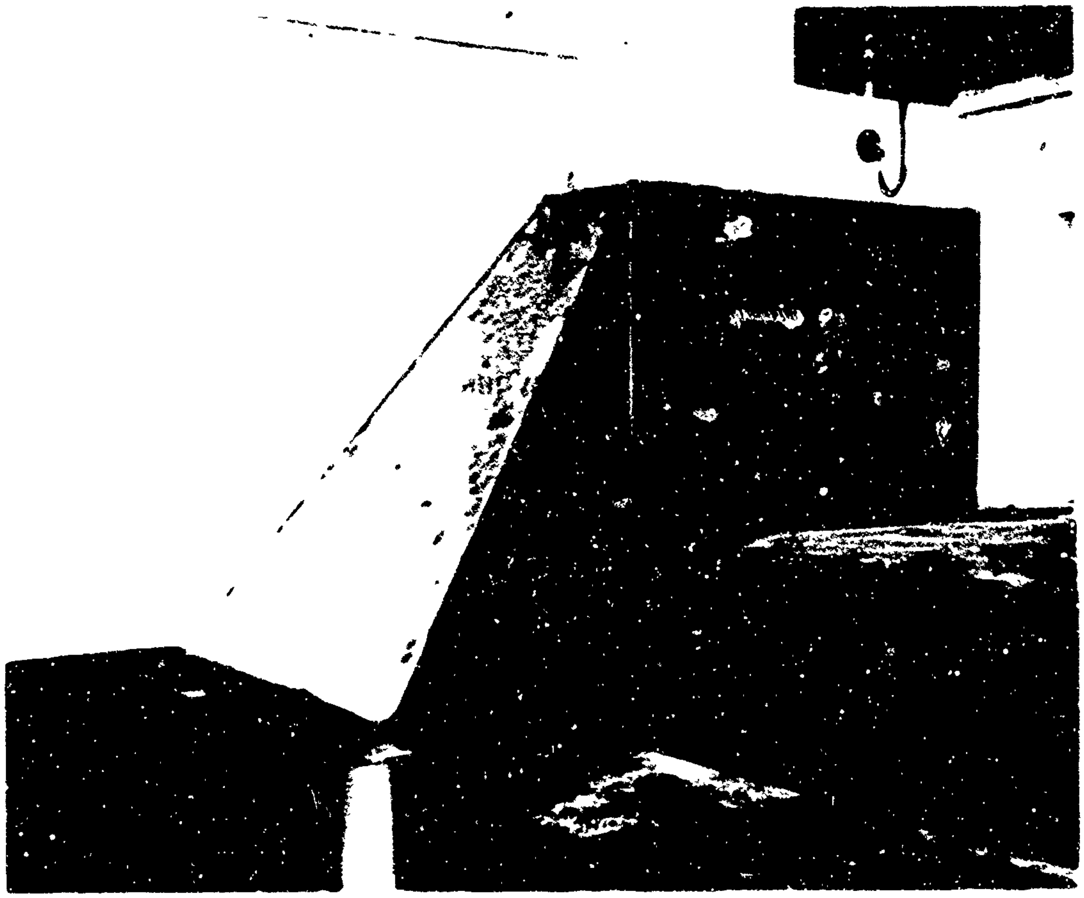


Figure 9-28. Heater Duct Transition Piece
(This photograph is for information only and should not be used as a criterion for the design of similar installations.)

cover panel. It should be noted that the protection against radio frequency interference will be destroyed unless the cable used for remote mounting is shielded

9-6.2 THERMOSTAT

The temperature control circuitry of environmental control units includes a thermostat which provides both heating and cooling control, usually within the range from 40° to 90°F. In small installations, the thermostat may be left in the unit, but in large installations, better control can be attained by removing the thermostat from the unit and mounting it in the conditioned space In the case of heaters, the temperature thermostat is always mounted outside the unit For proper control, it is very important to locate the thermostat properly. It should not be in a corner or other spot where there is no circulation, nor should it be located directly in the path of an air blast The thermostat should be placed in an exposed location, where there is normal circulation

9-6.3 DAMPERS

A damper is provided within environmental control units for controlling the amount of fresh air entering the unit If the inlet grille should be closed care should be taken to assure that enough air fresh or return passes over the evaporator to avoid the build-up of ice on the coils

Additional dampers are usually provided in the duct system, if one is used, so that air flow rates in different branches can be adjusted to meet various requirements

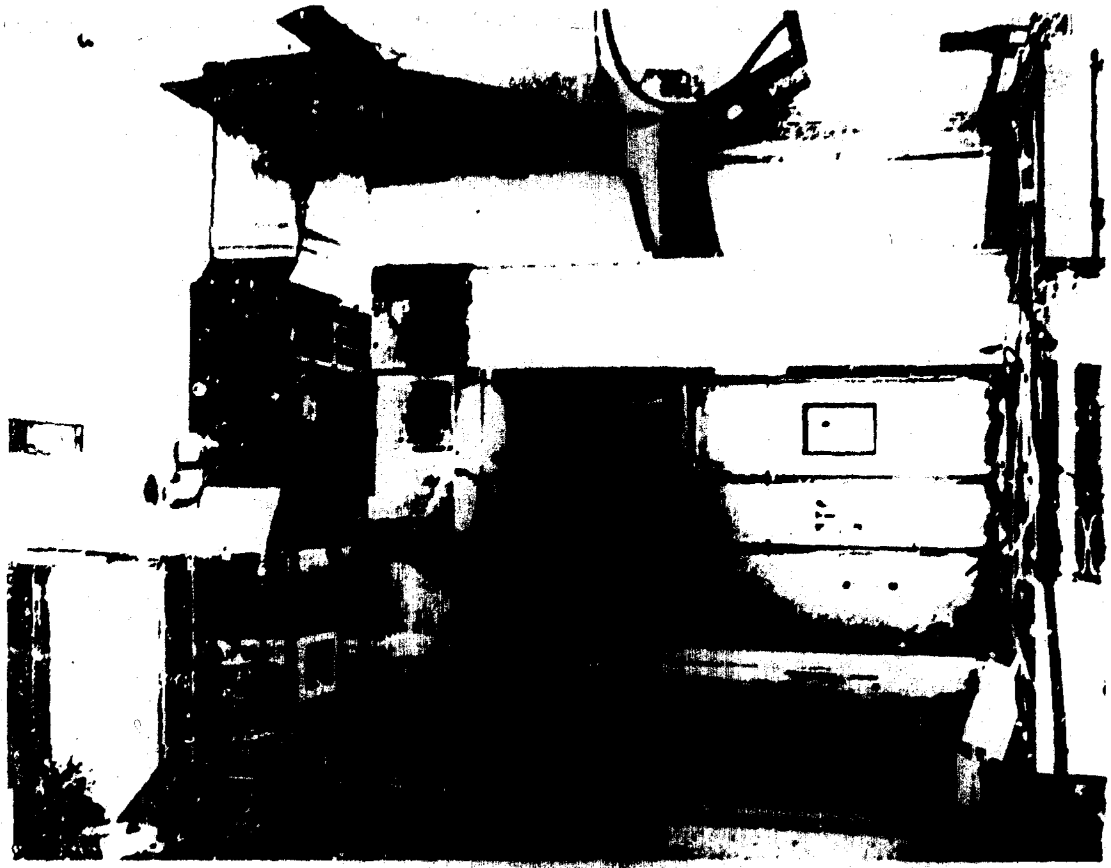


Figure 9-29. Heater and Air Conditioner Installation With Connecting Ductwork in Semi-trailer

(This photograph is for information only and should not be used as a criterion for the design of similar installations.)

9-6.4 AUXILIARY CONTROLS

There are a number of auxiliary safety controls which are part of the internal circuitry of the units and which, therefore, do not require any special attention during installation. These include the outside air thermostat, high temperature control, high pressure cutout switch, and back pressure regulator which are discussed in Chapter 4.

9-7 SAFETY CONSIDERATIONS

9-7.1 INTRODUCTION

As most of the safety features used in environmental control units are incorporated in the units, they do not require special installation procedures. These include items such as the overheat controls, high pressure cutout switch, and back pressure regulator – which are described in Chapters 4 and 6. This chapter considers only devices which are installed separately. A list of safety precautions to be taken when working with air conditioners is also included. Protection against chemical and biological contaminants is discussed in Chapter 11.

9-7.2 COMBUSTION HEATER OPERATION

It is essential to make sure that there be a continuous supply of fresh air to combustion heaters, so that there will be no chance of depleting the supply of oxygen in the controlled enclosure when such heaters remain in operation for extended periods. The combustion air intake line should be of the size

Figure 9-30. View of Semi-trailer Environmental Control Installation
(This photograph is for information only and should not be used as a criterion for the design of similar installations.)

recommended for the unit, it should be as straight and short as possible, and the inlet end should be free of obstructions.

It is also essential to insure proper exhaust of the combustion products. Installation of a condensation drain in the exhaust line, as described in par. 9-3.3.3, helps to prevent clogging of the exhaust line by the freezing of moisture in the exhaust gas.

As mentioned in par. 9-3.3.3, the heater exhaust should not be installed near any fresh air inlets or windows and doors.

9-7.3 EMERGENCY OVERRIDE SWITCH

In some applications, it may be anticipated that occasionally it will be essential to maintain environmental control even at the risk of temporarily overloading the environmental control units. In such cases, an emergency override switch should be provided to bypass all safety devices and thermostats to permit emergency operation of the system without normal protection against electrical, mechanical, or thermal overload[4]. This switch is to be used only for short periods when emergency conditions take precedence over the probability of major component failures. If the application requires it, an auxiliary method of minimal ventilation should be provided in case of component failures.

9-7.4 SAFETY PRECAUTIONS

The following list of safety precautions taken from Ref. 5 should be followed when working with air conditioners:

(1) Never remove any panels on the air

Figure 9-31. Heater and Air Conditioner Discharge Ducts in Semi-trailer

(This photograph is for information only and should not be used as a criterion for the design of similar installations.)

conditioning unit without first disconnecting the unit from the power source

"2 Keep hands away from the fans when the unit is operating.

"3 Never attempt any repairs or inspection of the electrical circuit unless the unit has been disconnected from the power source On units with main power line filters (RFI), the capacitors should be discharged electrically before attempting repair of the electrical circuit

"4. Stop the unit immediately if excessive vibration or unusual noises occur

"5. Do not use water on a motor fire Use CO_2

"6 If the motor or compressor should heat excessively, stop the unit immediately and investigate

"7 Should liquid Refrigerant-22 come in contact with the skin, the injury

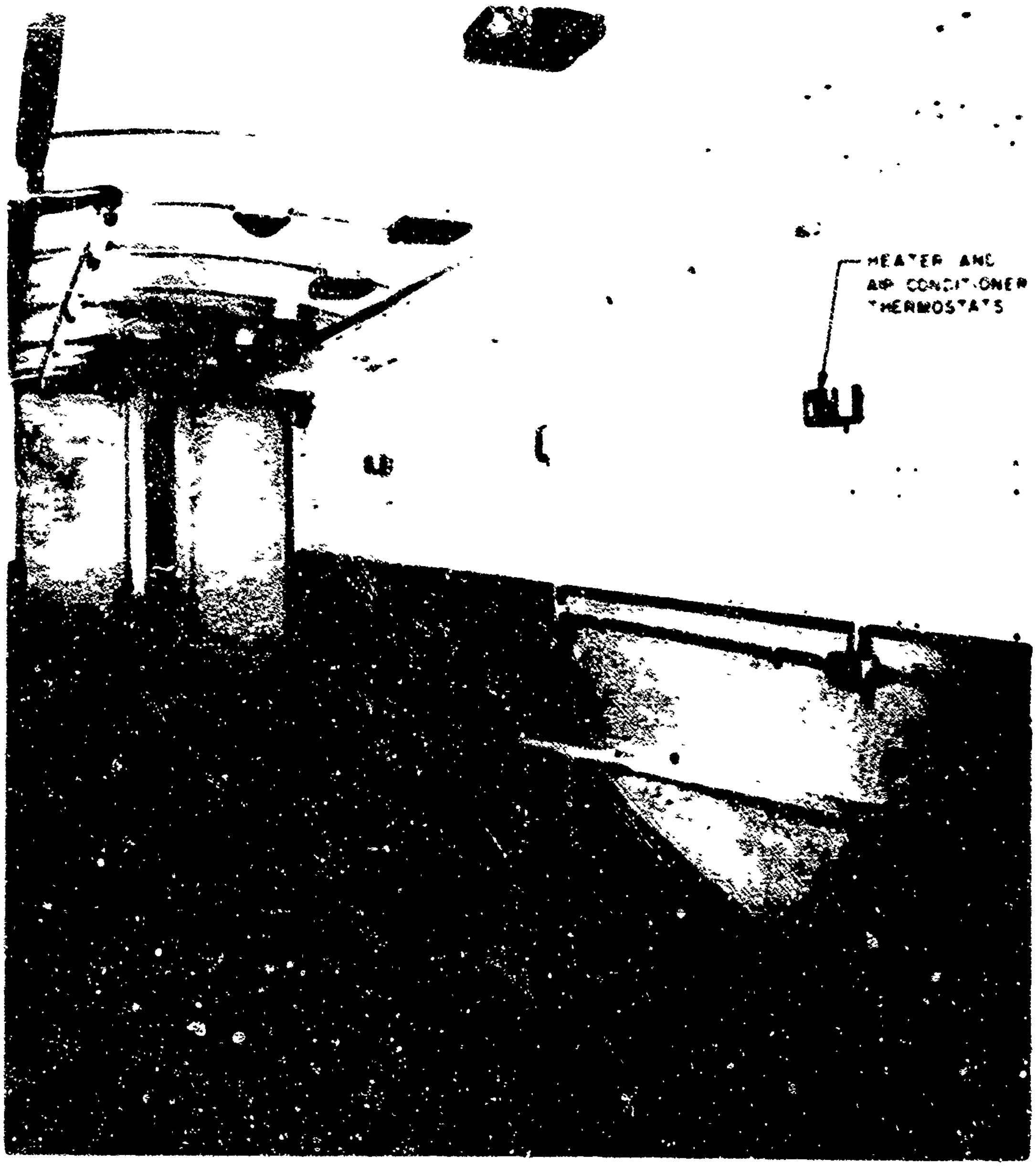


Figure 9-32. Completed Installation of Environmental Control Ductwork in Semi-trailer

(This photograph is for information only and should not be used as a criterion for the design of similar installations.)

should be treated the same as though the skin has been frostbitten or frozen.

"8. Do not work in a closed space where Refrigerant-22 may be leaking unless adequate ventilation is provided.

"9. Never use a torch on a Refrigerant-22 pipe line until it is determined that all gas has been eliminated from the line and that the area is well ventilated.

"10. Do not steam clean coils."

9-8 MAINTENANCE PROVISIONS

9-8.1 INTRODUCTION

The objectives of maintenance are to keep

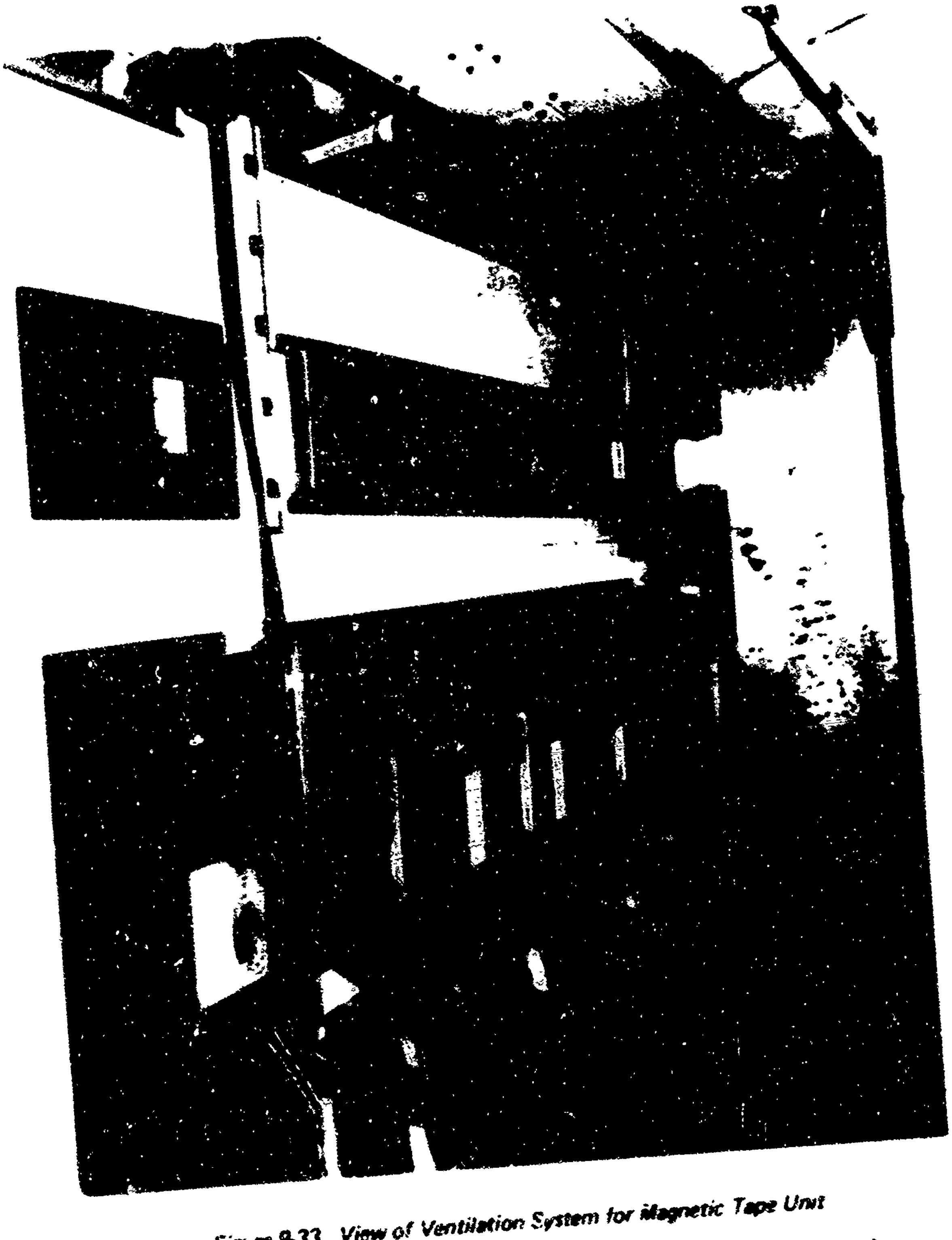


Figure 9-33. View of Ventilation System for Magnetic Tape Unit

(This photograph is for information only and should not be used as a criterion for the design of similar installations.)

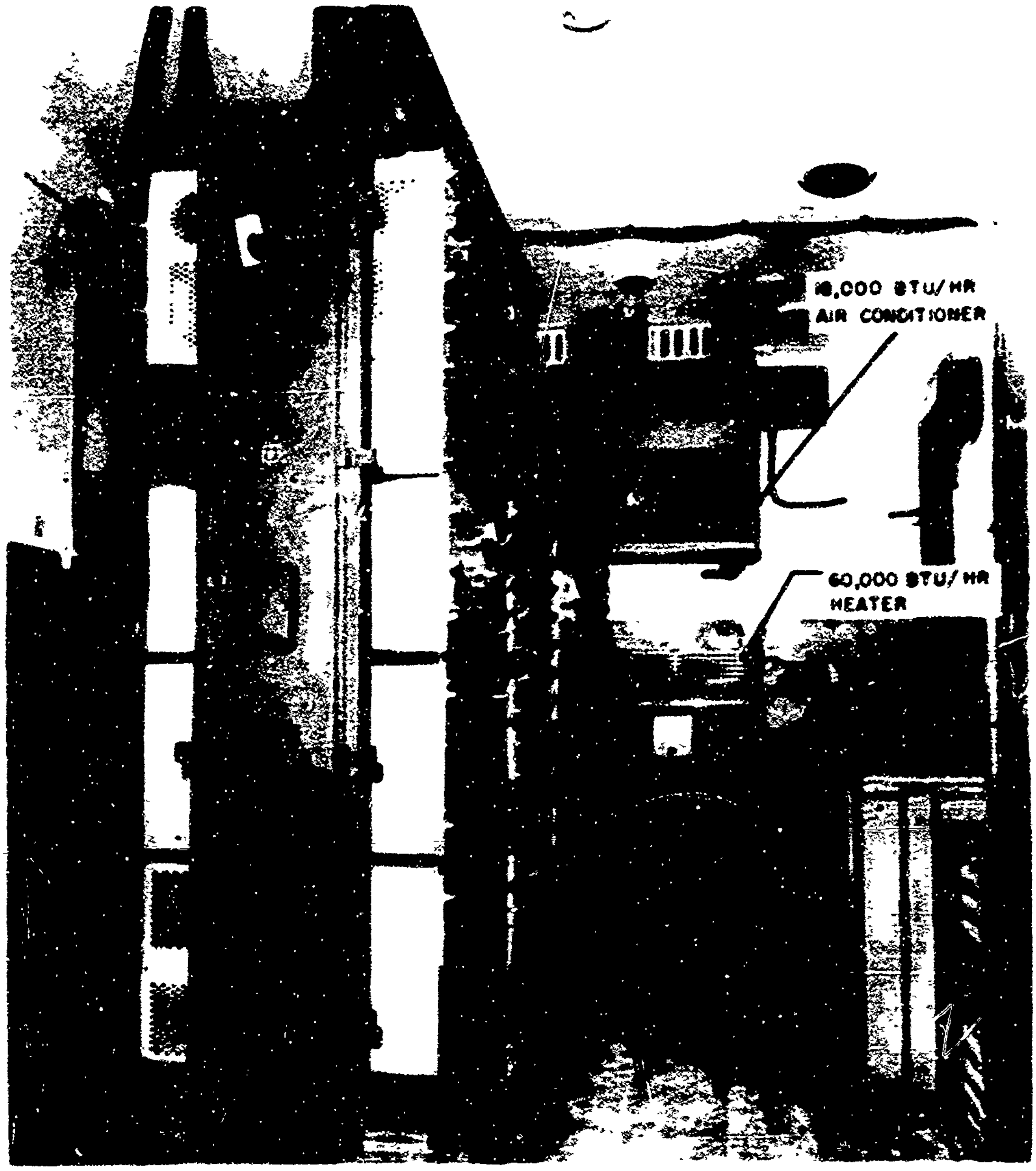


Figure 9-34. Interior View of Shop Van Showing Electronic Equipment and Environmental Control Units

(This photograph is for information only and should not be used as a criterion for the design of similar installations.)

equipment operating satisfactorily with as little effort and cost as possible*. Parts that require periodic inspection or servicing should be readily accessible. Provisions should be made for rapid removal and assembly of components that require servicing. If it is necessary to remove a panel to replace a component, it should be a simple operation. If the panel is fastened with screws, their number should be kept to a minimum.

There are two types of maintenance, preventive and corrective. Preventive maintenance deals with inspection, servicing, and minor repairs. Corrective maintenance in-

*An extensive list of maintenance objectives is given in Table 3-1 of Ref. 21, which may also be consulted for design guides pertaining to maintainability.

Figure 9-35. View of Completed Van Installation

(This photograph is for information only and should not be used as a criterion for the design of similar installations.)

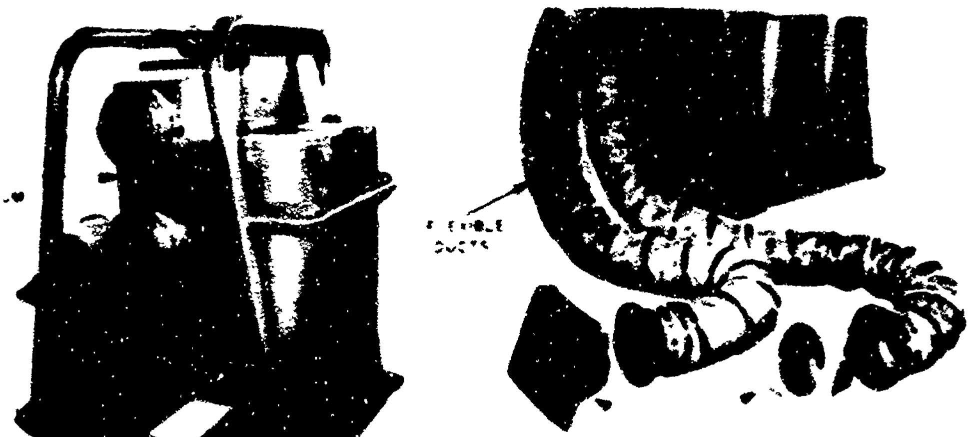
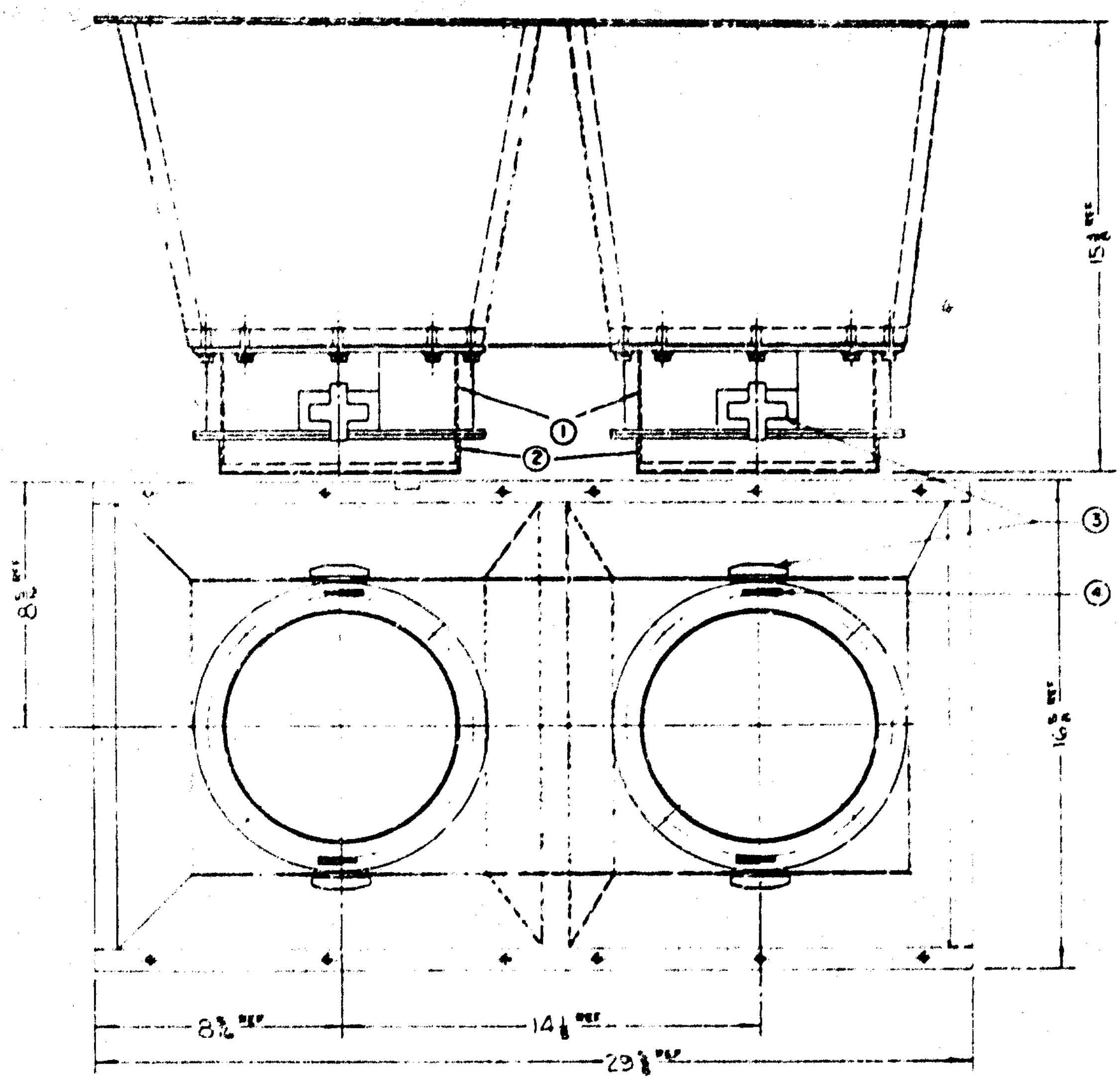


Figure 9-36. Conversion Materials Required for Flexible Duct Application



① MALE CONNECTOR
② COVER, OR FEMALE CONNECTOR OF FLEXIBLE DUCT (SEE FIGURE 9-38)
③ LOCK HANDLE
④ CAM LOCK (TIGHTENS AROUND PIN)

Figure 9-37. Drawing Showing Cam-lock Arrangement for Connecting Flexible Duct to Plenum
(Courtesy of Trane Company)

volves major repairs, replacement, and overhaul. The designer must always recognize the need to make any maintenance operations, particularly the preventive type, as simple as possible. Inspection, lubrication, filter cleaning, and oil changes, among others, should not be impeded by obstructions in the form of components that easily could have been located elsewhere. On the other hand, such ready accessibility is not so demanding for corrective maintenance, since more time is generally available for performing such maintenance. However, components which are likely to experience a relatively early failure should not be buried in inaccessible locations.

9-8.2 ACCESSIBILITY

It is important to plan mechanical connec-

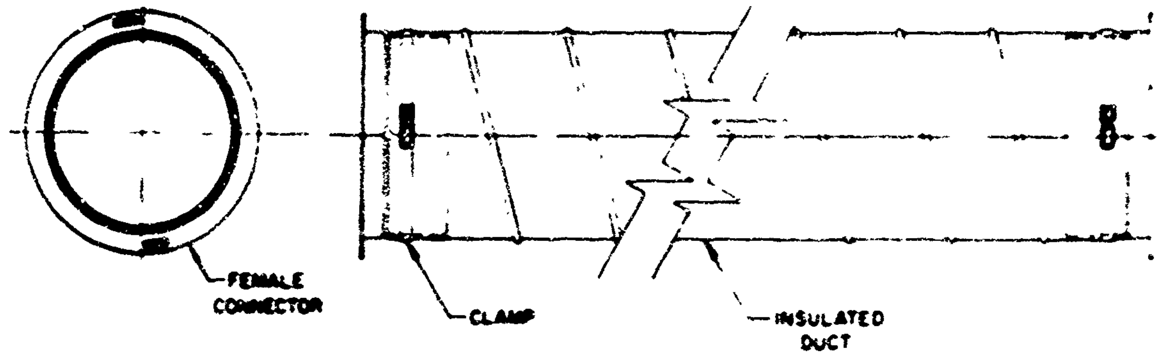


Figure 9-38. Drawing Showing Method of Attaching Flexible Duct to Female Connector With Metal Ring Clamp
(Courtesy of Trane Company)

tions so that maintenance points remain accessible. The arrangement should not make it difficult to perform operations which must be done regularly, such as the replacement of air and fuel filters. Indicators which must be viewed regularly, such as fuel-content and oil-level indicators, should be clearly visible. The refrigerant sight glass should also be easily seen. It is desirable that it be possible to perform common trouble-shooting operations without major disruption of the system. For example, it is desirable that service valves which enable a repairman to measure the intake and outlet pressures of the refrigeration system be readily accessible. Similarly, ports for recharging the cooling system should be readily accessible.

The conditioned air supply and return air grilles must be accessible for normal service and maintenance.

There have been cases where access door handles have become too hot to be handled due to solar radiation or because of nearness to a heat source, such as an engine exhaust line[22]. The use of materials of low thermal conductivity and low surface absorptivity will help alleviate the problem due to solar radiations. Heating from other sources can be reduced by care in location of parts that must be handled and by increasing the resistance of heat flow paths.

Ladders should be provided to facilitate access to environmental control units mounted too high to be reached otherwise. They should be light enough to be handled by one man. The time required for servicing and repair can be reduced by providing mounting brackets for the access ladders. If the ladders are to be used near power lines, wooden ones should be considered.

9-8.3 CODING OF PLUGS AND RECEPTACLES

The use of unique geometric shapes for matching plugs and their receptacles, and foolproof location of male and female parts are excellent means of avoiding mismatch. Color coding of plugs and receptacles is also an efficient means of assuring proper identification. However, if the number of plug-receptacle pairs exceeds eleven (preferably fewer) there could be a problem of color discrimination with variations in illumination. In such cases, numeric coding is preferable[3].

In selecting colors for color coding, one should try to accommodate color-weak people who do not perceive colors as normal people do. Yellow and blue are colors which such persons do not confuse[21].

9-8.4 PROTECTION AGAINST DETERIORATION

Environmental control units are designed

and manufactured in accordance with specifications which provide protection against deterioration by various agents such as fungus, moisture, temperature extremes, and salt atmosphere. Other components of the total environmental control system, such as ductwork and acoustic and thermal insulation, should be selected in accordance with the same protective criteria. Protection against deterioration is not a matter only of material selection, however. Proper design can diminish exposure of sensitive components to the deleterious agents.

Occasionally, damage results from unexpected sources. For example, the surfaces of components attached to air conditioners may become cold enough for condensation to form on them, which could contribute to intolerable deterioration. Increasing the thermal resistance of heat transfer paths to such surfaces may help prevent condensation. Where condensation is unavoidable, the use of moisture resistance materials will alleviate the problem.

9-9 NOISE CONTROL

9-9.1 INTRODUCTION

Problems of excessive noise or vibration originate in the periodic motion of a structure. The response of a structure to periodic energy input depends on its inertia and flexibility. If a structure has high inertia, the amplitude of oscillatory motion generated by the periodic energy input will be low, and the structure acts primarily as a path for energy transmission. If the inertia is low, the structure may undergo *forced* vibration, responding like a rigid body to the applied force. However, if one of the forcing frequencies of the input energy coincides with one of the natural frequencies determined by the flexibility of the structure, the phenomenon of resonance causes a cancellation of the opposing reactions resulting from the mass and rigidity of the structure, and greatly amplified vibrations result.

The techniques of isolation and absorption are those commonly used to control excessive noise and vibration. Mechanical isolation is best suited for controlling forced vibrations, and acoustical absorption is the best way of handling airborne noise.

In the case of equipment used with mobile shelters for military operations, the control of vibration is complicated by several factors

(1) Not only must the noise level inside the shelter be kept to an acceptable level, but also the noise level sensed in the external operational area must be considered.

(2) Mobility requirements demand that the equipment be as light in weight as possible, but this tends to increase noise problems because reducing mass lessens vibration damping.

(3) The rigors of usage in military operations require design of rugged equipment with a minimum of resilient interconnection and a minimum of relative motion between various components. Thus the effect of noise control by vibration isolation is minimized.

9-9.2 AIR NOISE CONTROL

It is well to introduce this topic by recommending a step which can be taken to prevent the generation of avoidable acoustic noise. This is to minimize the power available for conversion to sound by keeping the fan power as low as possible. The acoustic power generated by a fan in an air-moving system varies as the fifth power of the flow rate[7]; therefore, even a little excess fan power can result in substantial avoidable acoustic noise. The required flow rate should be calculated as accurately as possible, and any provision for excess air flow capacity should be kept to a minimum.

The common technique of air noise control is acoustical absorption which has the objective of reducing noise by intercepting airborne acoustical energy. The air is allowed to flow through small passages where its energy is dissipated by friction against the walls of the

passages. One may use baffles or acoustic tiles made of porous materials readily penetrated by air. The efficiency of absorption depends primarily on the ratio of the thickness of the absorbent material to the wavelength of the impinging acoustical signal, the greater the ratio, the greater the absorption. Thus, acoustical tiles are more effective in reducing high-frequency noise than low frequency noise. However, frictional loss is not a very efficient mechanism for reducing noise, and it may not be effective in controlling noise of high intensity. In such cases, one may use acoustical barriers, which may range from rigid enclosures of the source to special earmuffs for the receiver.

Prefabricated mufflers are available for insertion in ducts. Their primary advantage is that a given noise reduction can be attained in a shorter length of duct than would be required by other means. Although there may be a substantial pressure drop through the muffler section, it may be much smaller then the pressure drop through the length of lined duct that would be needed for equal noise attenuation. The net amount of pressure loss is diminished if the muffler can be installed where there is a straight, downstream section of duct long enough for pressure recovery to occur. Manufacturers provide pressure-drop, noise-attenuation, and installation data for the various models of mufflers on the market*.

A multiple-layer material which combines one or more lead septums with alternating layers of polyurethane foam is available for noise and vibration control†. The material combines vibration damping, noise absorption, and sound transmission reduction. It is intended primarily for application directly to the equipment which generates the unwanted noise.

Steps that can be taken to reduce acoustical noise generated by air flow include

(1) Line air plenum walls with acoustic insulation.

(2) Use ducts with acoustic lining or apply lining to metal ductwork. The duct should be lined for a distance of at least 10 ft, starting at the environmental control unit.

(3) Install a noise attenuator at the air intake and discharge openings. (See Fig. 9-39.)

(4) Install acoustic absorbing material at strategic locations within the enclosure. The use of acoustic ceiling tile is an example of this method.

(5) Install barriers between the sound source and the listener. If the noise to be attenuated originates in the environmental control unit, the supply and return air should be ducted through the barrier. The radiating sound path should be made as indirect as possible and the barriers should be as massive as practical to insure [illegible] acoustic transmission loss.

(6) Choose inlet and outlet register sizes and duct sizes which do not yield high air velocities.

(7) Design the duct system for minimum flow resistance (see par. 9-5.1).

(8) Use the least air flow rate that will meet the environmental control requirements.

9-9.3 MECHANICAL NOISE CONTROL

Mechanical noises originate in machinery which transmits cyclical forces to its supports and thence to the surrounding structure. To isolate the structure from such disturbing forces, separators are installed between the source of mechanical vibrations and the area from which they are to be excluded. Separators consist of coil springs, elastomer pads, or combinations of them. The natural frequency of the separators should be con-

*Among suppliers of such mufflers are The Aeroacoustic Corp., Amityville, N.Y., Industrial Acoustics Co., New York, N.Y., and Koppers Co., Inc., Baltimore, Md.
†Manufactured by The Soundcoat Company, Inc., 515 Madison Ave., New York, N.Y. 10022.

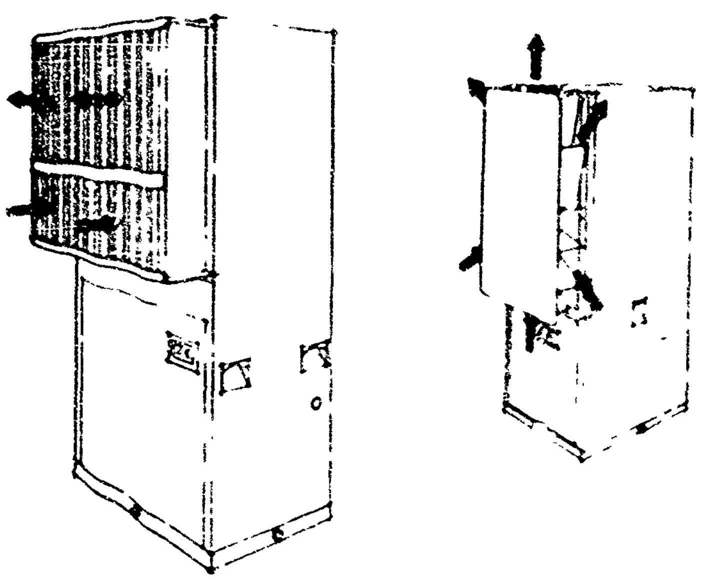


Figure 9-39. Attachments for Attenuating Noise at Intake and Discharge Openings of Environmental Control Units

siderably lower than the frequency of the disturbing force. In addition to preventing direct contact between the vibration sources and other parts of a structure, the separators increase the impedance mismatch at the boundary and proportionately decrease the efficiency of energy transmission. The use of shock absorbers on an automobile engine is an example of the isolation technique.

The disturbing frequency f_o may be defined as the lowest frequency of forced vibration, i.e., the vibration generated by rotating or reciprocating machinery. As a general rule, isolation against the lowest disturbing frequency of the system will provide a greater degree of isolation for the higher frequencies. In the case of a belt-driven centrifugal fan, there would be two discrete disturbing frequencies of vibration generated, that of the drive motor and that of the fan. The fan usually operates at a lower rotating speed than the motor, therefore, if the suspension for this system can isolate vibration produced by the fan, it will provide a greater amount of isolation for vibrations produced by the motor.

The natural frequency f_n is the frequency at which a vibration isolator will resonate under a given load when loaded and released. This frequency can be expressed as

$$f_n = 188\sqrt{C/L} \text{ cycles/min} \qquad (9\text{-}1)$$

where

C = spring constant of the isolator, lb/in.

L = load supported by the isolator, lb

The transmission constant T of the isolator expresses the percentage of the total vibratory force which is passed through the isolator at each frequency. An equation has been developed to calculate this constant from the physical characteristics of the system

$$T = 100\left[\frac{1}{\left(\frac{f_o}{f_n}\right)^2 - 1}\right] \qquad (9\text{-}2)$$

However, Eq. 9-2 is usable only in isolators having low hysteresis losses. The shear-loaded mounts and the pad-type isolators have such high hysteresis that the above equation does not provide a good estimate of the transmission constant. Values of transmission constants for typical isolators are shown in Table 9-5.

TABLE 9-6

TRANSMISSION CONSTANTS FOR TYPICAL ISOLATORS[24]

Isolation material	Loading	Maximum static deflection in.	Average natural frequency cpm	Percent transmissibility for disturbing frequencies, cpm, of 350	500	650	800	1000	1200	1750	[illegible]
Steel spring	Select spring to suit load	3	109	10	5	3	2	1	0.5	Negligible	
		2	155	17	7	4	3	2	1.5	0.5	Negligible
		1	108	40	16	9	6	4	2.5	[illegible]	
Double deflection rubber mountings[1]	Size and durometer to suit[2]	0.5	305		61	38	18	10	8	[illegible]	[illegible]
Single deflection rubber mountings[1]	Size and durometer to suit[2]	0.25	450				40	24	18	6	2
Double thick ½ in. ribbed rubber	60 psi	0.1	505					33	2.	[illegible]	[illegible]
Single thick ½ in. ribbed rubber	60 psi	0.05	710						33	18	4
2 in. thick compressed cork[3]	20 psi	0.08	1415[4]								[illegible]

[1]Transmissibilities for single and double deflection rubber mountings allow for inherent damping
[2]Durometer should not exceed 70
[3]Standard density
[4]By Cox

A new method of noise control, which has proved to be a powerful remedy for resonant vibrations, is constrained-layer damping[23]. The method employs a rigidly-backed layer of viscoelastic material applied directly to the surface of the vibrating structure. The constraint of the rigid backing causes the layer of viscoelastic material to undergo shear deformation when the structure vibrates, and the mechanical vibration energy is significantly dissipated by conversion to heat. The efficiency of the method depends not only on the energy-dissipation capacity of the damping layer but also on the efficiency with which energy is transferred from the primary vibrating structure to the damping layer; the latter requirement makes it imperative that there be suitable mechanical coupling of the three layers.

Method of reducing mechanical noise include

(1) Mount equipment on vibration isolators.

(2) Separate inlet and outlet environmental control unit from shelter openings or ductwork by use of a resilient transition piece, such as asbestos canvas (see Fig. 9-40). A flexible connection is particularly recommended if the unit is mounted on isolators.

(3) Noises caused by duct flexing (due to thermal expansion and contraction or variations in internal air pressures) can be controlled by bracing, use of sheet metal of adequate gage, and avoiding high width depth ratios.

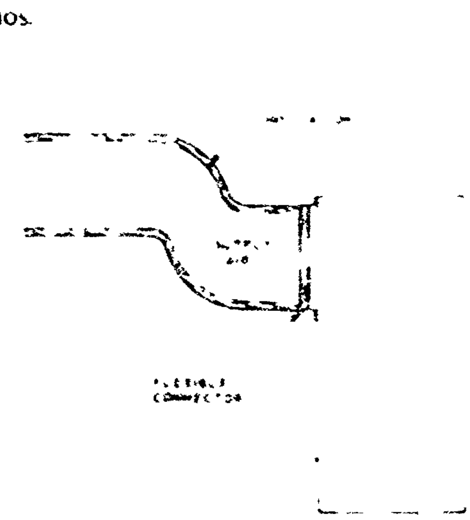


Figure 9-40. Attenuation of Noise in Discharge Ductwork

REFERENCES

1. Standards of U.S. Army Human Engineering Laboratories, Aberdeen Proving Ground, Md.

   a. HEL Standard S-2-64A, *Human Factors Engineering Design Standard for Vehicle Fighting Compartments*, June 1968.

   b. HEL Standard S-6-66, *Human Factors Engineering Design Standard for Wheeled Vehicles*, Sept. 1966.

   c. HEL Standard S-6-68, *Human Factors Engineering Design Standard for Communication Systems and Related Equipment*, Dec. 1968.

2. Trane Engineering Bulletin, *Military Air Conditioner Selection and Application*, Section B-10, 67-86, The Trane Co., La Crosse, Wisconsin, 25 June 1968.

3. *Study Report, Electronic Test Set No. 3, Vol. 4: Mechanical Considerations*, ATE-MTE-L-4, Radio Corp. of Am., Aerospace Systems Div., Burlington, Mass. (AD-476 234).

4. A. J. Reynolds and S. T. Hovey, *Mobility Aspects of a System Design for a Deployable Reconnaissance Extraction Facility*, Technical Report No. RADC-TR-65-222, Reconnaissance-Intelligence Data Handling Branch, Griffiss Air Force Base, New York, July 1965.

5. *Manual for Trane Compact, Vertical, Military Air Conditioners*, The Trane Co., La Crosse, Wisconsin, July 1968.

6. N. B. Hutcheon, *Air-Conditioning and Comfort*, Occupational Health Review 17(2), 3-11 (1965). Also available as a reprint, NRC 8625, National Research Council, Ottawa, Canada, July 1965.

7. ASHRAE, *Handbook of Fundamentals*, Amer. Soc. of Heating, Refrigerating and Air-Conditioning Engineers, Inc., New York, N.Y. (1967).

8. F. A. Govan, *Air-Conditioning Design*, National Research Council, Publication 709, National Academy of Sciences, Washington, D.C., 1959.

9. R. J. Kenny, "Noise in Air-Moving Systems", *Machine Design* 40, 138-150 (1968).

10. C. R. Hoffman, *Modified T-5 Barracks-Controlled Climatic Heating Studies*, Tech. Rep. R286, U.S. Naval Civil Engrg. Lab., Port Hueneme, Calif., 12 May 1964 (AD-600 519).

11. R. J. Kenny, "Fans and Blowers", *Machine Design* 40, 151-173 (1968).

12. *Guide and Data Book, Systems and Equipment 1967*, Amer. Soc. of Heating, Refrigerating and Air-Conditioning Engineers, Inc., New York, N.Y., 1967.

13. R. D. Madison and W. R. Elliot, "Friction Charts for Gases Including Correction for Temperature, Viscosity and Pipe Roughness", *Heating, Piping and Air Conditioning* 18(10), 107-112 (Oct. 1946).

14. R. G Huebscher, "Friction Equivalents for Round, Square and Rectangular Ducts", ASHVE Trans. 54, 101 (1948).

15. C. Berry, *Fan and Flow*, The Industrial Free Press, New York, N.Y., 1954.

16. *Carrier Design Manual*, Chapter 2, "Air Duct Design", Carrier Air Conditioning Co., Syracuse, N.Y., 1960.

17. *Trane Air Conditioning Manual*, The Trane Company, La Crosse, Wisconsin, 39th printing, July 1967.

18. *Duct Manual and Sheet Metal Construction for Ventilation and Air Conditioning Systems, Section I, Low Velocity Systems*, Sheet Metal and Air Conditioning Contractor's National Association, Inc., 1963.

19. *Guide and Data Book, Applications for 1966 and 1967*, Amer. Soc. of Heating, Refrigerating and Air-Conditioning Engineers, Inc., New York, N.Y., 1966.

20. *Installation, Operation and Maintenance Instructions, Vehicular Environment Control System*, Harrison Radiator Division, General Motors Corporation, Lockport, New York (AD-481 331).

21. AMCP 706-134, Engineering Design Handbook, *Maintainability Guide for Design*.

22. V. F. Galbig, *Engineering and Environmental (Desert) Test of Semitrailer, Refrigerator, Van, 15-Ton, 4-Wheel, XM347E1*, Report No. OTA/TB5-1401/480, TW-501/14, U.S. Army Ordnance Test Activity, Yuma, Arizona, Nov. 1959. (AD-229 076).

23. T. P. Yin, "The Control of Vibration and Noise", Scientific American 220, 98-106 (1969).

24. W. E. Whale, "Isolating Equipment for Vibration Control", Heating, Piping and Air Conditioning 38, 122-5 (1966).

CHAPTER 10

COOLING OF ELECTRONIC EQUIPMENT

10-1 COOLING METHODS

The method most commonly used to cool electronic equipment is to circulate outside filtered air through the cabinets containing the equipment. Temperature regulation can be achieved by varying the rate of air flow. If adequate cooling cannot be attained with outside air, air conditioning must be employed, but this may be needed only for cooling equipment which is extremely temperature sensitive. Heat convected from electronic apparatus into the space occupied by personnel can be reduced by isolating the instrument racks and providing a separate exhaust, directly to the outside of the van, for the air used in cooling the apparatus. If most of the electronic equipment does not produce a high temperature rise in the cooling air, provision of a separate exhaust to the outside may be limited to those components that produce a high temperature rise and that would otherwise overheat the return air. Some air conditioning installations are designed to circulate the conditioned air to the operator's space first, then to the electronic cabinets. Although this is not the most efficient method of cooling electronic equipment, the installation may be less costly in cases where CBR protection requirements must be met. An undesirable feature of this procedure is that it may cause the operator's space to be too cool.

Usually the cooling air enters at the bottom, rear side of the electronic cabinets, and blowers located at the top draw the air upward through the cabinets. A slight underpressure in the cabinets prevents the cooling air, the temperature of which may rise considerably, from leaking into the personnel quarters. It is important to take filter losses into account when choosing the blowers for these cooling systems. If necessary, ducts and vanes may be used inside the cabinets to direct the flow of air to particular hot spots.

The proper design of a cooling system for electronic equipment requires a knowledge of the temperature limits within which the equipment can function properly. Different parts of a given system may have quite different tolerances. A computer, for example, may have a memory core capable of withstanding temperatures up to 120°F, while the magnetic tapes may operate satisfactorily only within the range of 70° to 90°F. For critical components, it is essential to assure that air of suitable temperature flows over the component at a rate adequate to maintain the temperature of the component within its tolerance. The problem can be solved using heat transfer theory in the case of simple geometries. However, if the configuration is complex and the temperature tolerance is critical, it may be best to make an experimental determination of the cooling air requirements.

A practical example of the analysis of an electronic equipment cooling problem is given in Ref. 1. Appendix D of Ref. 1 analyzes the feasibility of using an outside air cooling loop to reduce the air-conditioning requirement, and Appendix C analyzes the air flow patterns through racks of electronic equipment consisting mostly of printed cards stacked vertically in baskets.

Another practical example of electronic equipment cooling can be found in Ref. 2, which considers the problem of controlling the temperature of van- and sheltered-enclosed electronic equipment with particular

emphasis on its relation to equipment performance and reliability.

Heat pipes, which transfer heat basically by vapor transport and capillary action, provide a new method of removing waste heat and leveling temperature in electronic equipment. The uses of these thermal conductance devices are reviewed in Ref. 3.

Thermoelectric cooling methods being developed may provide better solutions for some problems, particularly for spot cooling[4].

10-2 COMPUTATION OF COOLING REQUIREMENTS

The heat load on the environmental control system due to electronic equipment is equal to the heat value of the electrical power dissipated as heat inside the controlled enclosure. Except for power transmitted from the enclosure (as radio waves, for example) this will be equivalent to the operating power of the equipment. This load often accounts for a major portion of the total cooling load.

Since different kinds of electrical equipment have varying usage requirements, a so-called *usage factor* is defined as the expected power requirement for a four-hour period divided by the power requirement for continuous, full-load operation for a four-hour period.

The total electronics load q_{el} is[5]:

$$q_{el} = 3.413\ \Sigma\,(\text{Full Load Power in watts}) \times (\text{Usage Factor}),\ \text{Btu/hr} \qquad (10\text{-}1)$$

The summation extends over all equipment in the controlled enclosure.

One method of computing the amount of cooling air required involves use of the psychrometric chart, as illustrated by the example which follows

A transmitter requires 1 kW of power, and the maximum allowable ambient temperature for its components is 150°F. Conditioned air of 63°F dry bulb and 60°F wet bulb (saturation) temperature is available for cooling. Assuming turbulent flow, (i.e., good mixing) what cooling air rate in cubic feet per minute is required?

In Fig. 10-1, Point A designates the state point of the processed cooling air. Since moisture is neither added or removed during the heating process, the state point moves along a horizontal line to Point B, which represents the maximum allowable temperature (150°F). The difference between the enthalpies associated with points B and A, is 48.0 − 26.4 = 21.6 Btu/lb. The mass rate w of air delivery required is:

$$w = \frac{q_{el}\ (\text{Btu/hr})}{\text{change in enthalpy of air (Btu/lb)}}\ ,\ \text{lb/hr} \qquad (10\text{-}2)$$

Therefore, to remove heat at the rate of 1000 W or 3.413 × 1000 Btu/hr, the rate of air flow required is 3413/21.6 = 158 lb/hr. On the psychrometric chart, one can read the specific volume v of this air in the cool state, which is 13.4 ft³/lb. Then, the volume rate Q of air delivery can be computed.

$$Q = \frac{w\ (\text{lb/hr}) \times v\ (\text{ft}^3/\text{lb})}{60\ (\text{min/hr})}\ ,\ \text{cfm} \qquad (10\text{-}3)$$

Thus, to perform the cooling work for the equipment of this example, (158 × 13.4)/60 = 35.3 cfm of cool air are necessary.

The calculations can be simplified for commonly encountered causes by using the following formula:

$$Q = 3.1\ P/\Delta T \qquad (10\text{-}4)$$

Here Q is the required flow of air (cfm), P is the electric power in watts and ΔT is the difference between the entrance temperature of the cooling air and the maximum allowable

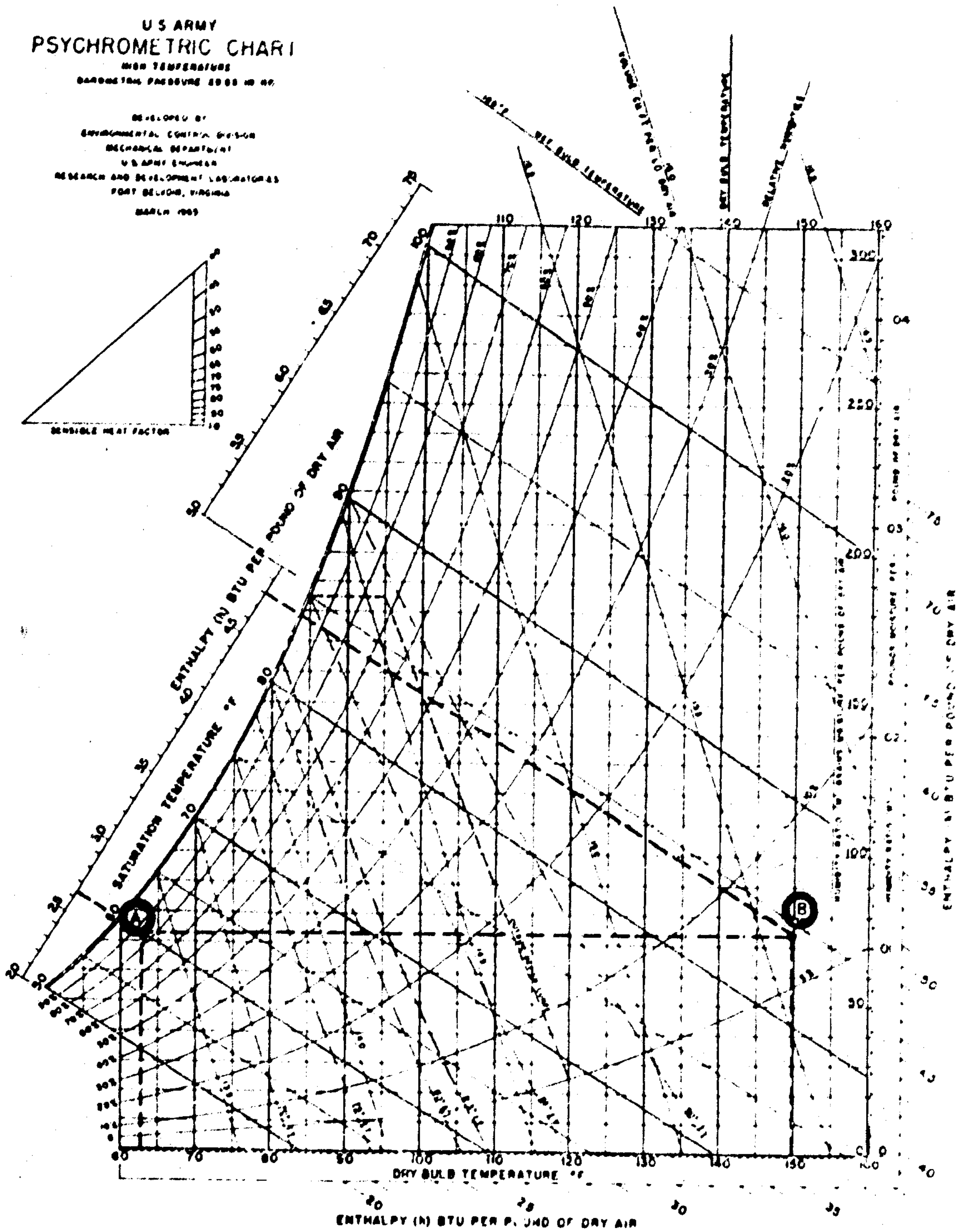


Figure 10-1. Diagram To Illustrate Solution of Problem on Cooling of Electronic Apparatus

ambient temperature in the equipment. For the given example one obtains:

$$Q = \frac{3.1 \times 1000}{(150 - 63)} = 35.6 \text{ cfm}$$

This value of cool air delivery compares well with the result of the more detailed calculation.

REFERENCES

1. Radio Corp. of Am., *Study Report, Electronic Test Set No. 3, Vol. 4: Mechanical Considerations*, ATE-MTE-L-4, Radio Corp. of Am., Aerospace Systems Div., Burlington, Mass. (AD-476 234).

2. U. S. Army Test & Evaluation Command, *Special Study Report of Heating and Cooling Systems of Vans and Shelter-Inclosed Electronics Equipments*, U. S. Army Electronic Proving Ground, Fort Huachuca, Arizona, March 1965 (AD-820 730).

3. C. H. Dutcher, Jr., and M. R. Burke, "Heat Pipes – A Cool Way to Cool Circuitry", *Electronics*, 43, 94-100 (1970).

4. *Study of Thermoelectric Cooling of Electronic Equipment*, Final Report LMSC/HREC A783745, NASA Accession No. N68-15786, Lockheed Missiles and Space Co., Huntsville, Alabama, January 1967.

5. R. E. Franseen, *Cooling and Heating Load Calculations for Environmental Control Equipment Applications*, U. S. Army Engineer Research and Development Laboratories, Fort Belvoir, Va., 10 September 1965.

CHAPTER 11

CHEMICAL, BIOLOGICAL, AND RADIOLOGICAL CONSIDERATIONS

11-1 INTRODUCTION

The purpose of CBR protection is to safeguard personnel and equipment from chemical, biological, or radiological warfare agents including radioactive dust. The term "collective" indicates that protection is afforded to a large group or area, in contrast to an individual in the open. There are four categories of CBR protection*.

(1) *Category A.* CBR protection equal to the standard personnel gas masks while eliminating the human element (time-to-mask, mask fit, and danger of continuous exposure may be disregarded). This includes an air lock to allow shelter entrance or exit. (The schemes of collective protection systems for Category A are illustrated in Fig. 11-1.)

(2) *Category B.* CBR protection equal to standard personnel gas masks while eliminating the human element; no air lock.

(3) *Category C.* Only personnel gas mask protection.

(4) *Category D.* Shelter space sealed from external infiltration and inert as to ventilation.

The objective of CBR environmental control for mobile systems is to provide a clean atmosphere within which personnel can live and work without special clothing or masks. This requires that purified air be supplied to the protected area of the vehicle, van, or shelter at a pressure high enough to prevent the infiltration of chemical and biological agents and radiological particulates. Collective protection is also provided for vital equipment whose proper functioning could be impaired by dust and the effects of antimateriel agents.

There are a number of reports that consider the collective protection of vehicles, vans, and shelters*; and notable among these are the following.

(1) *Feasibility and Design Study Reports*

(a) Ref. 5 considers the collective protection for the AN/TSQ-47 system of shelters. The appendix of the report gives a detailed analysis of the shelter system requirements, including a computer program for CBR calculations. The body of the report includes plans of CP systems for several shelters.

(b) Ref. 6 is a report on a design study of collective protection for the M292 Expansible Van.

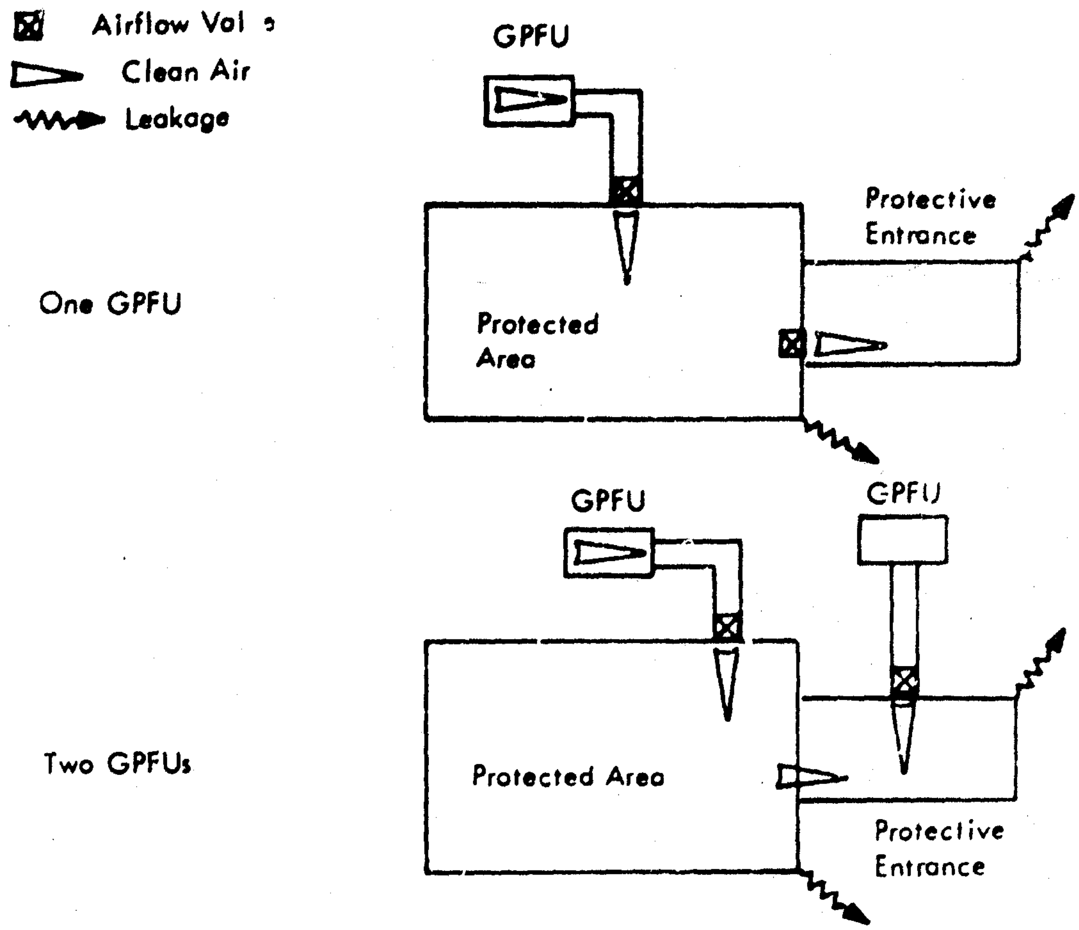
(c) Ref. 7 considers various approaches to adapting collective protection equipment to the AN/GSM-44 Shelter System. In particular, the shelter inside temperatures were computed for different collection protection equipment (CPE) systems.

(d) Ref. 8 reports on a feasibility and design study of the application of collective protection to the various subsystems of the AN/MSG-4 Antiaircraft Defense System.

(e) Ref. 9 reports on a feasibility study

*Chemical Corps Board Report 10-50.

*The collective protection of tanks and structures requiring field assembly[2,3,4] is not considered in this chapter.



GPFU = Gas-Particulate Filter Unit

Figure 11-1. Category A Collective Protection[1]

of the collective protection of the AN/MRC-6? and AN/MRC-73 Radio Terminal Set Shelters.

(f) Ref. 10 is an interim report on the development of the M9A1 Collective Protector, including a discussion of filter design problems.

(2) *Test Reports*

(a) Ref. 11 is a report on an engineering test of a collective protection unit. Measurements of the temperature rise of the air caused by the action of the collective protection equipment and vehicle leakage are of particular interest.

(b) Ref. 12 reports on test of two models of flightline taxi designed to protect personnel being transported in a chemical and biological environment.

(3) *Modular Collective Protection Equipment.* Ref. 1 is the final report on the exploratory phase of a program to establish a system of modular equipment to provide collective protection to a variety of vehicles, vans, and shelters. (Two of the concepts of modular configurations are shown in Fig. 11-2.) It was concluded that modular collective protection equipment should be provided to cover the airflow range of 50 to 600 cfm. The study included concept studies of CPE

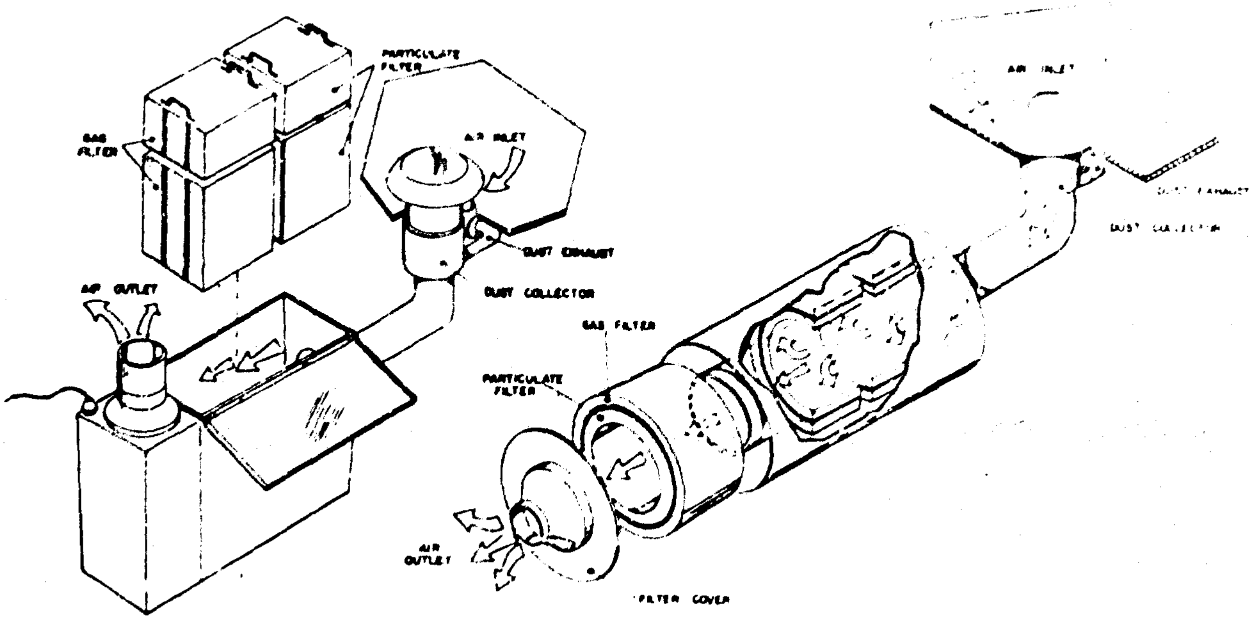


Figure 11-2. Exploded Views of Two Concepts for Modular Configurations of Collective Protection Equipment[1]

components. Subsequent reports[13,14] discuss the development of the components.

11-2 GENERAL CONSIDERATIONS OF COLLECTIVE PROTECTION

11-2.1 KINDS OF CONTAMINATION

Chemical and bacteriological agents can be employed as a gas, an aerosol, and in the form of solid particles.

Radioactive particulates cause radiation hazards which come predominantly from fall-out settling on roofs and other exposed surfaces. Mobile equipment usually cannot be adequately protected by radiological shields because of the additional weight required.

11-2.2 AIRFLOW REQUIREMENTS

A survey conducted by the Donaldson Co. revealed that in the majority of applications to mobile systems, airflow between 100 and 600 cfm is required[1]. By taking into account the elasticity of system designs, four design airflows are recommended. Fig. 11-3 illustrates the design airflows and the range they cover. Systems requiring airflows greater than 600 cfm can be assembled from several smaller units.

11-2.3 PRESSURIZATION

The purpose of overpressure in the protected enclosures is to prevent the inflow of outside air by ways other than through the collective protection system. Therefore, the pressure within the enclosure must be higher than the stagnation pressure caused by wind velocity and/or the speed of the moving vehicle. A design value is 50 mph of combined wind and vehicle velocity, which corresponds to a stagnation pressure of 1.2 in. H_2O[1]. This pressure must be added to the van static pressure. Correct pressure is normally maintained by controlling the influx of air into the protected enclosure. In some applications the outflow air is regulated by an anti-backdraft value.

11-2.4 PERFORMANCE

In the designing of a collective protection

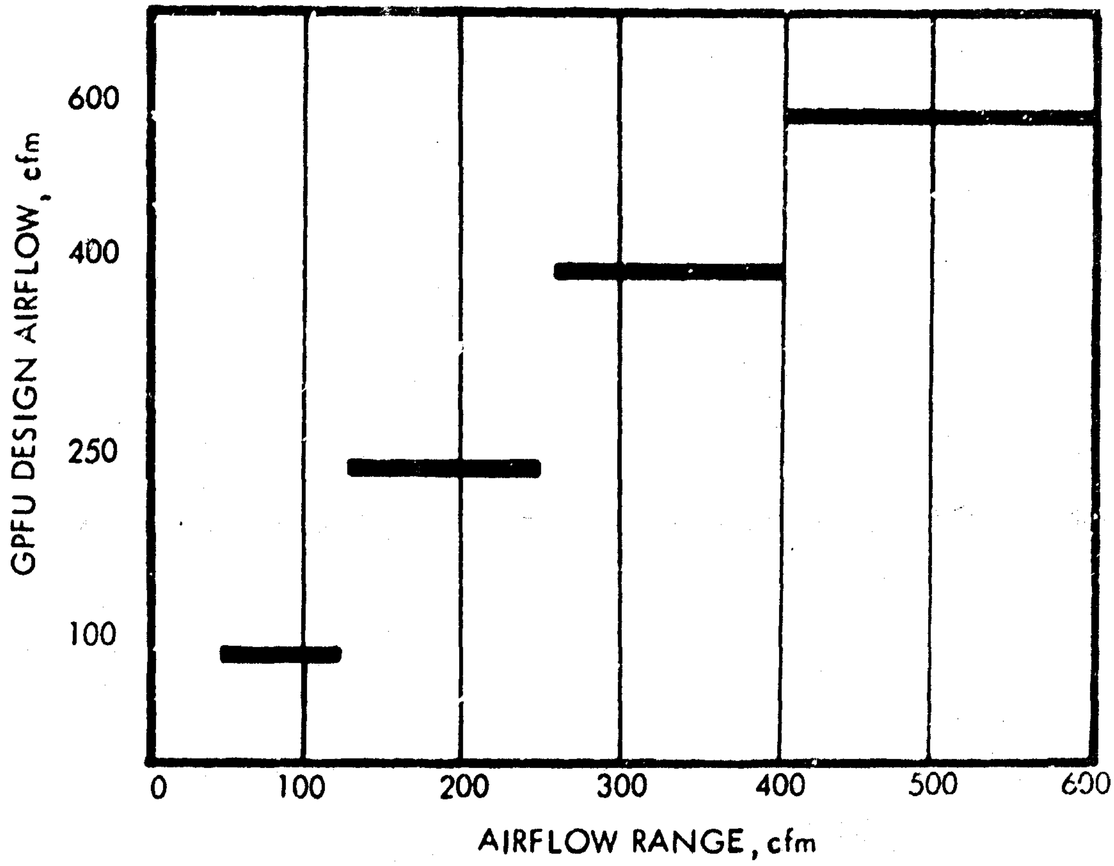


Figure 11-3. Recommended Gas-particulate Filter Unit (GPFU) Design Air Flows and Ranges[1]

system, design goals should be met in the following order of priority:

(1) Performance

(2) Reliability

(3) Maintenance

(4) Weight, size, and power.

11-2.5 CLEAN ROOMS

Repair shops for delicate electronic equipment require clean environments. These conditions are obtained by providing laminar air flow directed vertically toward the work surface at a velocity of 100 fpm. Customary standards for controlled environments are Class 100,000 per FED-STD 209, which stipulates 100,000 particles per ft^3 of 0.5 micron and larger, or 700 particles of 5 microns and larger. Usually, ambient air is passed through a coarse filter and then through a high efficiency filter for particles of 0.3-micron size.

11-3 COLLECTIVE PROTECTION SYSTEM COMPONENTS

11-3.1 INTRODUCTION

The following basic components are required to provide collective protection for a mobile enclosure such as a van or shelter:

(1) A source of purified air, essentially free of CB agents

(2) A means of pumping the air into the enclosure at a pressure high enough to prevent infiltration of CB agents

(3) An air lock to allow entry and exit of personnel without drastic loss of pressure and to minimize the possibility of contaminating the enclosure.

11-3.2 AIR INLET PROTECTOR

The air inlet opening must be protected against a variety of hazards. Particularly susceptible to adverse effects of the environment are the gas-particulate filter units (GPFU) and the blades of the blowers. It is the function of the air inlet protector to protect this equipment against damage from ingestion of solid or liquid materials. The air inlet protector may be provided with a rain shield and, if the application requires it, a deep fording valve, which automatically closes and prevents ingestion of water when the vehicle fords through deep water. While the air inlet protector also shields against larger objects such as rocks and twigs, bullet proofing is usually not attempted. An example of an air protector is shown in Fig. 11-4. The air inlet should be located to avoid the excessive pick-up of dust and, where applicable, engine exhaust and gun fumes. Dust concentrations are highest at ground level, and may be two to three orders of magnitude lower at 8 ft above ground. Typical dust concentrations that may be encountered are given in Table 11-1. An extensive list of dust concentrations that may be encountered in military activities is given in Ref. 15.

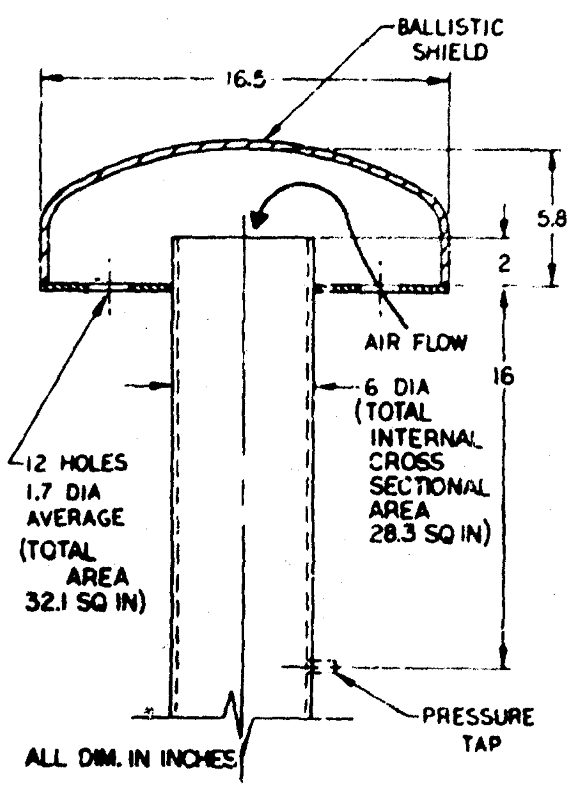


Figure 11-4. Air Inlet Protector[1]

11-3.3 PREFILTER

A prefilter or dust collector should remove about 90% of the dust. For efficiency testing, Standard AC (coarse) Test Dust is used*. Simple prefilters consist of several layers of expanded aluminum sheets, fibrous glass, or metal gauze. Cyclone type dust collectors, even though more complex, are preferred because of continuous performance with less maintenance. Fig. 11-5 shows a schematic drawing of a dust cyclone. Fig. 11-6 shows typical arrangements using cyclones for continuous dust removal. The two arrangements shown differ in the amount of dust to which the main fan propeller blades are subjected.

11-3.4 BLOWERS

A detailed discussion of blowers, especially a comparison of basic types, may be found in Ref. 1. Design procedures for identifying requirements and selecting a booster blower are given in Ref. 5, in conjunction with an analysis of CBR protection for a system of shelters.

Blowers should be able to operate for 500 hr without maintenance or repair. Of particular concern to the design engineer are the noise levels generated.

11-3.5 PARTICULATE FILTERS

The purpose of the particulate filter is to filter out solid particles such as dust, bacteria, and liquid droplets having diameters down to about 0.3 micron or smaller. Design requirements are: removal of 99.97% of 0.3 micron

*Supplied by AC Spark Plug Div.

TABLE 11-1*

DUST CONCENTRATIONS FOR DIFFERENT TRANSPORT CONDITIONS

Terrain	Vehicle Type	Vehicle Speed, mph	Sampler Distance from Vehicle, ft	Sampler Height Above Ground, ft	Dust Concentration, g/ft^3
Desert	Tracked	20 - 30	20	5	0.10 - 0.20
Desert	Heavy Tracked	10	20	5 - 6	0.05 - 0.10
Cross Country	Heavy Tracked	10 - 20	20 - 40	5	0.005 - 0.05
Gravel Road	Heavy Tracked	10 - 20	50	6	0.0005 - 0.005

*Taken from Ref. 1, which summarizes information in Ref. 16.

particles, and filter and prefilter to have a dust capacity capable of handling the intake of coarse test dust at a rate of 0.025 g/ft^3 for 24 hr. During the service life, the air resistance of the filters should not increase to a level where proper functioning of the collective protection system is impaired. Typical particulate filter material is a glass fiber media (MIL-F-51089). A conventional filter panel design is shown in Fig. 11-7. Attention must be paid to the proper sealing at the edges of the filter material. (MIL-E-51065 is applicable to the sealant.) For further details of the construction of particulate filters, consult Ref. 17. A list of existing military particulate filters is given in Table 11-2.

11-3.6 GAS FILTERS

The gas filter shall be capable of providing protection against all gaseous toxic warfare agents. As a measure of this protection, the filter shall have an operational safe life at its rated airflow greater than 20 min when tested with a concentration of 10 mg/liter of phosgene. The absorbent agent is, e.g., type ASC whetterized charcoal (MIL-C-13724A). One filter design (Types E61 and E65) is shown in Fig. 11-8. The cloth fines media indicated in Fig. 11-8 prevent fine charcoal dust from escaping. This fine dust is created by attrition due to vibrations in the installations. Other critical components of the filter construction are gaskets and sealants. The design of gas filters is covered in Refs. 1 and 6. Table 11-3 gives a list of presently available gas filters. There are plane and cylindrical constructions. The major deficiencies of these filters at present are their size, weight, and sensitivity to malfunction due to vibration.

11-3.7 FILTER UNITS

The U. S. Army has standardized a number of module filter units which include as components a prefilter, particulate filter, gas filter, and an integral blower unit. The characteristics of some of these units are listed in Table 11-4. An arrangement is shown in Fig. 11-9. The aim of present and future development efforts will be to construct the various components of a collective protection system in module form which ensures savings in maintenance and repair. It will then be desirable to reduce the number of standardized modules to a minimum. For applications with high airflow requirements, a combination of several modules in parallel may become necessary. A schematic of such a concept is shown in Fig. 11-10.

11-3.8 CONTROL OF PRESSURE

A means of regulating the pressure is an antibackdraft valve. It allows air to flow from the inside of the enclosure to the outside, but not in the reverse direction. In its simplest form, as illustrated in Fig. 11-11, the valve consists of a hinged plate which lifts up when the internal pressure works against its weight. The adjustable weight position determines the pressure drop across the valve. This construc-

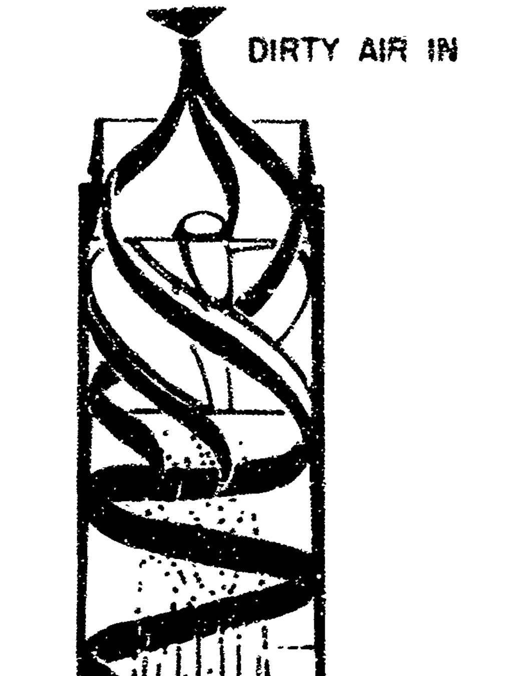


Figure 11-5. Straight-flow Dust Separator Tube Cyclone Principle[1]

tion is very susceptible to vibrations, but the dashpot helps to dampen them. Other forms of regulating valves consist of motorized louvers or blades actuated by pressure switches. Pressure sensors and control loops are necessary in the latter case and, in designing such a control loop, care must be exercised to avoid unstable modes which could lead to pressure cycling annoying to the shelter occupants.

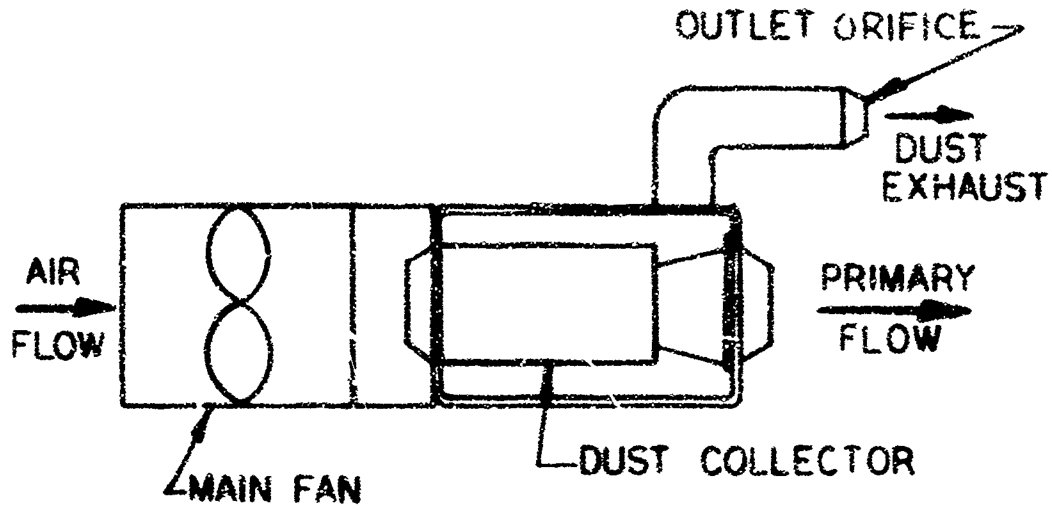
11-3.9 CONTROLS

The controls required for collective protection systems comprise switches, indicators, circuit breakers, and warning devices. In particular, some shelter systems have both visual and audible alarm indicators which alert the operator if the pressure in the enclosure drops below the danger point. A manually operated switch serves to turn off the audible alarm, which automatically resets for a next time. One component of the control panel is an elapsed time meter which indicates maintenance interval requirements of the system.

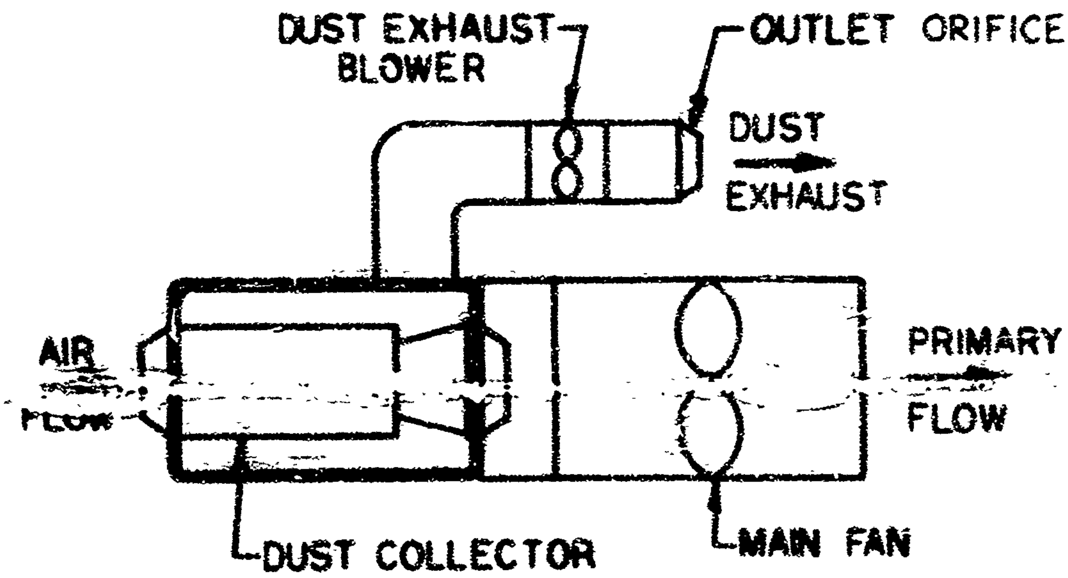
11-3.10 PROTECTIVE ENTRANCES

A protective entrance is used to provide a means of safe entry and exit of personnel into and from the protected area. This maintains the protective integrity of the protected area during entry and exit. The pressure of the protective entrance is maintained at a level higher than atmospheric pressure but lower than the pressure inside the shelter. This prevents possible contaminated air in the protective entrance from penetrating into the shelter. In the latest systems, the protective entrance is neither heated nor cooled.

Ease and rapidity of installation are of paramount importance with protective entrances. Construction of protective entrances for vehicles, vans, and portable shelters is of fabric, such as butyl coated nylon, and a supporting frame. The passage doors are usually sealed by means of spring-loaded interlocking flaps or by zippers. A small window with blackout curtains is provided. For more details see Ref. 1. Procedures for decontamination of personnel and material entering the protective entrance area are treated in the system operator maintenance manuals.



(A) Dust Collector Downstream



(B) Dust Collector Upstream

Figure 11-6. Cyclone Arrangements for Continuous Dust Removal[1]

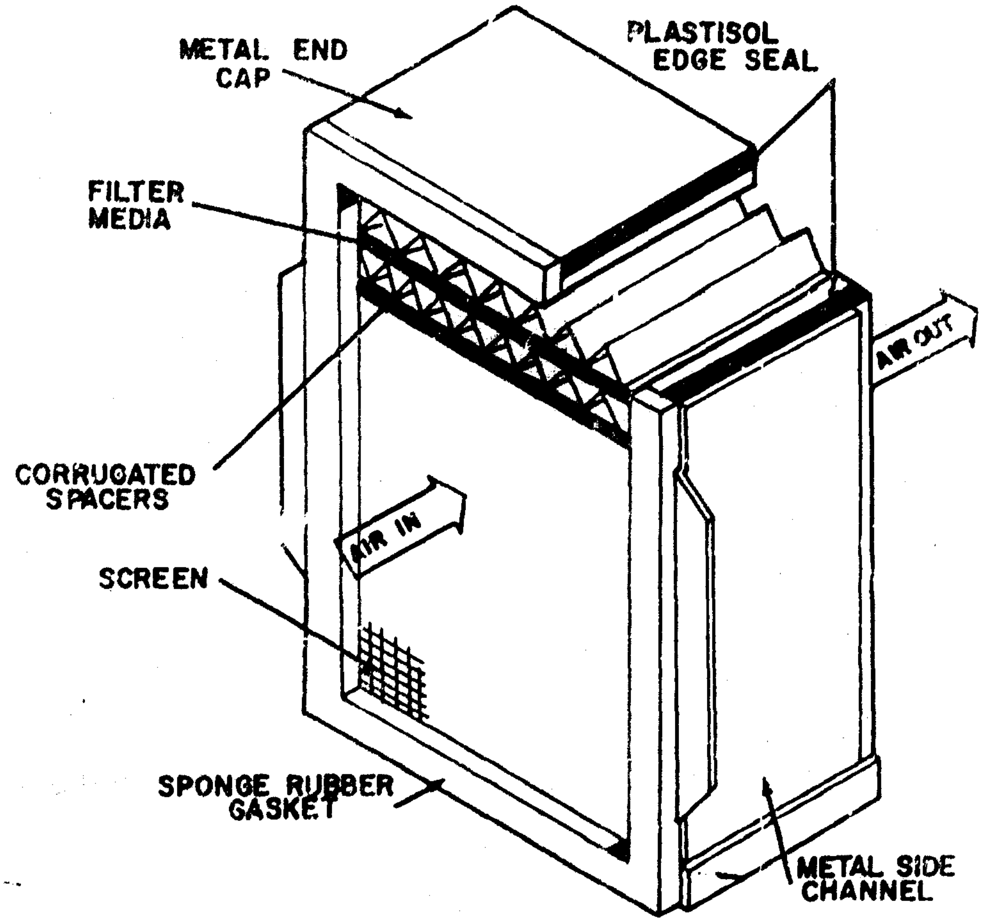


Figure 11-7. Typical Panel-type Particulate Filter Construction[1]

11-4 INSTALLATION AND MOUNTING

Some of the vehicles, vans, and shelters that require collective protection specify that the protective filter be mounted inside the protected shelter, while others specify that it be mounted outside. The internal application is usually specified for combat vehicles, such as the Main Battle Tank and Mechanized Infantry Combat Vehicle, to provide protection of the filter from battle damage. Vehicles, vans, and shelters with logistic missions generally do not require that the filter be mounted within the protected area, both because there is no need for protecting it and because internal space is limited. In addition, the noise generated by the fans would be objectionable to the usage of some shelters. In some instances filters must be mounted inside the van or shelter. If radiation protection is required, internal filter installations will require a radiation shield.

The internal and external mounting of the filter require different designs to protect personnel within the shelter from CB agent contamination. When the unit is mounted within the protected enclosure, the main fan or air supply is mounted downstream from the filters so that the air is pulled through the filters. This provides a pressure within the filter housing lower than that within the surrounding protected shelter. Thus, any leakage in the filter housing results in clean air from the enclosure leaking into the filter housing. For external mounting, the filter is

TABLE 11-2

EXISTING PARTICULATE FILTERS FOR COLLECTIVE PROTECTION SYSTEMS*

Filter No.	Rated Flow, cfm	Overall Dimensions, in.	Maximum Air Resistance, in. H_2O
M9A1	150	24 x 24 x 3-1/16	1.0
M13	12	7 x 5-1/2 x 1-7/8	0.7
M19	20	7 x 5-1/2 x 4-1/8	0.94
M24	150	22 x 21 x 2	1.0
M22	400	21-3/4 x 16 x 9	1.1
C18R1	600	24 x 24 x 5-7/8	1.25
C19R1	1,200	24 x 24 x 11	1.25
C20R1	5,000	48 x 48 x 11	1.25
C30R1	2,500	24 x 46-1/2 x 11	1.0
C47	2,400	43 x 31-1/2 x 6	2.0
XM35**	400	24-3/4 x 12-3/4 x 6	0.79
XM37**	250	24 x 14 x 4	0.58

*List provided by Physical Protection Lab, Defense Development and Engineering Laboratories, Edgewood Arsenal, Maryland.

**Type classification anticipated by end of 1QFY71.

TABLE 11-3

EXISTING GAS FILTERS FOR COLLECTIVE PROTECTION SYSTEMS*

Filter No.	Rated Flow, cfm	Overall Dimensions, in.	Air Resistance, in. H_2O	10 mg/liter Phosgene Gas Life, min
M18	10	5-5/8 dia. x 9-1/4	1.4	31
M12A1	12	5-7/8 x 6-15/16 x 3	4.2	28
C22R1(1)	600	25-1/2 x 25-1/2 x 29-1/4	1.25	48
C32R1(2)	1,200	25-1/2 x 25-1/2 x 51-5/8	1.50	48
C29R1(3)	2,500	25-1/2 x 48 x 51-1/2	1.50	48
C23R1(4)	5,000	48 x 48 x 50-3/4	1.50	48
M21	100	22-1/2 x 21 x 2-11/16	2.3	33
M10	150	24 x 24 x 2-11/16	4.5	46
M23	150	22 x 21 x 2	3.6	22
C49	220	24 x 43 x 1-1/4	2.1	18.5
XM34(5)	400	24-3/4 x 12-3/4 x 12	3.6	22.3
XM36(5)	250	28 x 14 x 7	2.7	31

(1) Assembly consisting of 10 C10 modules

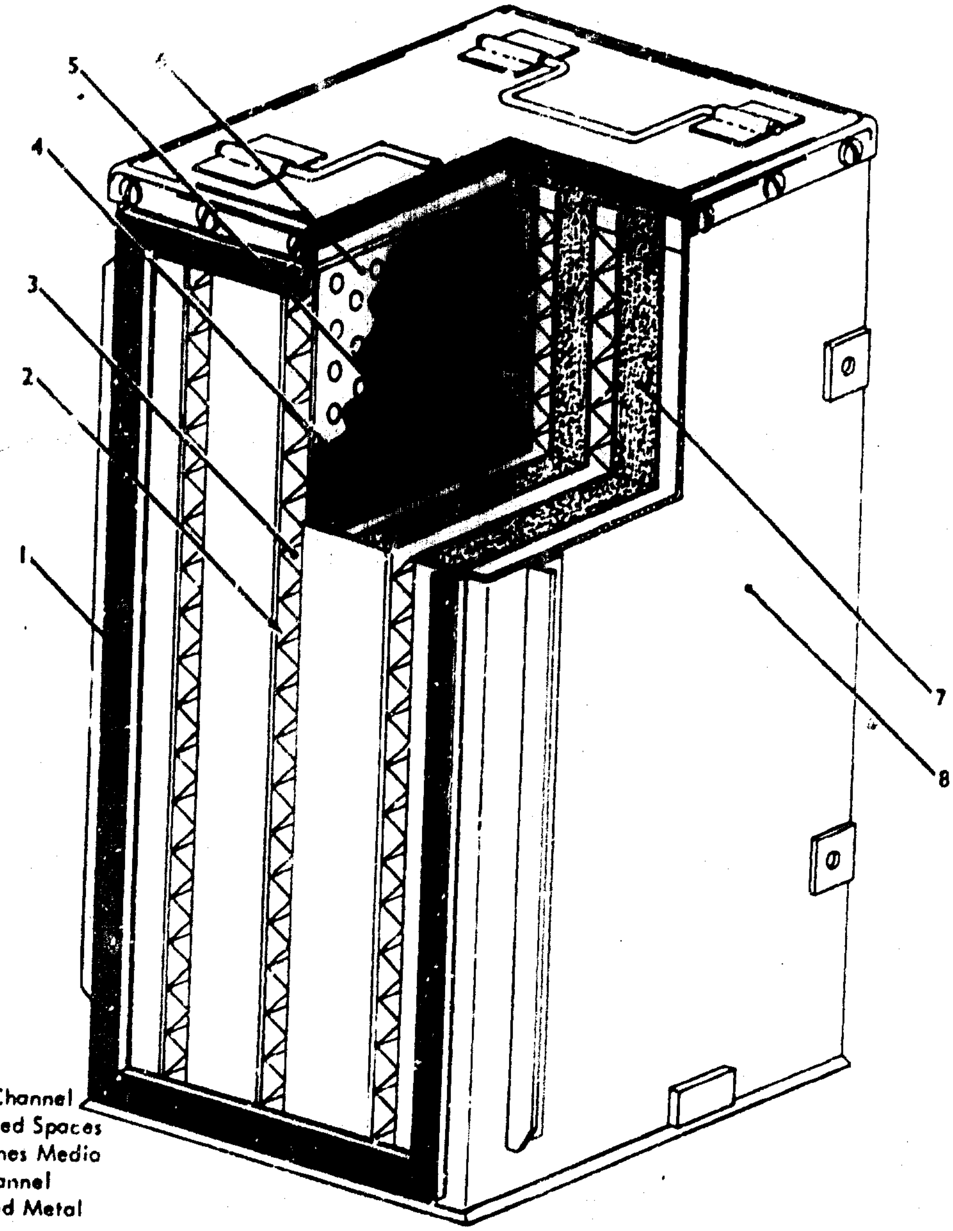
(2) Assembly consisting of 10 C31 modules

(3) Assembly consisting of 10 C21 modules

(4) Assembly consisting of 20 C21 modules

(5) Type classification anticipated by end of 1QFY71

*List Provided by Physical Protection Lab, Defense Development and Engineering Laboratories, Edgewood Arsenal, Maryland.



1. Gasket
2. Outlet Channel
3. Corrugated Spaces
4. Cloth Fines Media
5. Inlet Channel
6. Perforated Metal
7. Charcoal
8. Housing

Figure 11-8. Typical Latest-design Gas Filter[1]

TABLE 11-4

STANDARD CB FILTER UNITS*

CBR Unit No.	Gas Filter No.**	Gas Filter Rated Flow, cfm	Gas Filter Air Resistance, in. H_2O	Particulate Filter No.Δ	Particulate Filter Rated Flow, cfm	Particulate Filter Air Resistance, in. H_2O	Size, in.	Weight, lb	Rated Flow, cfm
M6A1	M10(2)	150	4.5	M9(2)	150	1.0	24 x 34 x 39	400	300
M8A3	M12A1	12	4.2	M13	12	0.70	13 x 8 x 6	27	12
M9A2	C22R1	600	1.0	C18R1	600	1.25	81 x 31 x 40	300	600
M10A2	C32R1	1200	1.0	C19R1	1200	1.25	135 x 31 x 40	1000	1200
M11A2	C29R1	2500	1.0	C30R1	2500	1.00	138 x 52 x 40	1500	2500
M12A2	C23R1	5000	1.0	C20R1	5000	1.25	158 x 53 x 60	2000	5000
M13A1	M18(2)	10	1.4	M19	20	0.94		21	20
M15	C46(11)	220	2.1	C47	2400	2.0	84 x 47 x 36	1200	2400
M18	M23(2)	150	3.6	M24(2)	150	1.0	40 x 24 x 16	160	300
M19	M21	100	2.3	M22	400	1.1	64 x 25 x 21	382	400
XM47†	XM34	400	3.6	XM35	400	0.79	52 x 23 x 38	466	400
XM51†	XM36	250	2.7	XM37	250	0.58	30 x 26 x 13-1/2	212	250

*List provided by Physical Protection Lab, Defense Development and Engineering Laboratories, Edgewood Arsenal, Maryland.

**See Table 11-3. One filter is used unless indicated otherwise by number in parentheses.

ΔSee Table 11-2. One filter is used unless indicated otherwise by number in parentheses.

†Type classification anticipated by end of 1QFY71.

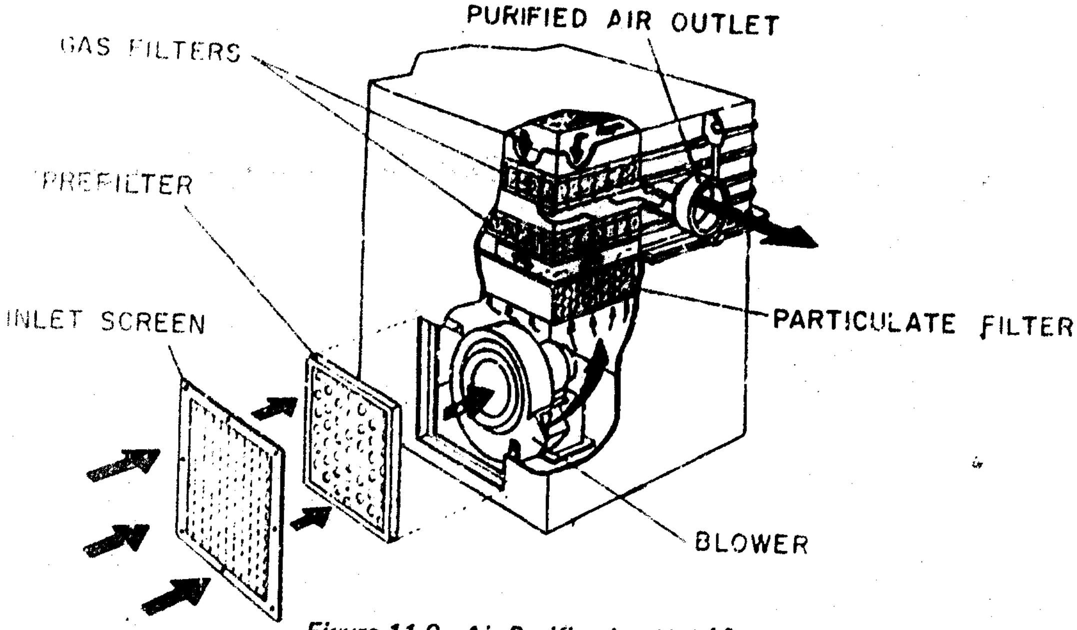


Figure 11-9. Air Purification Unit[18]

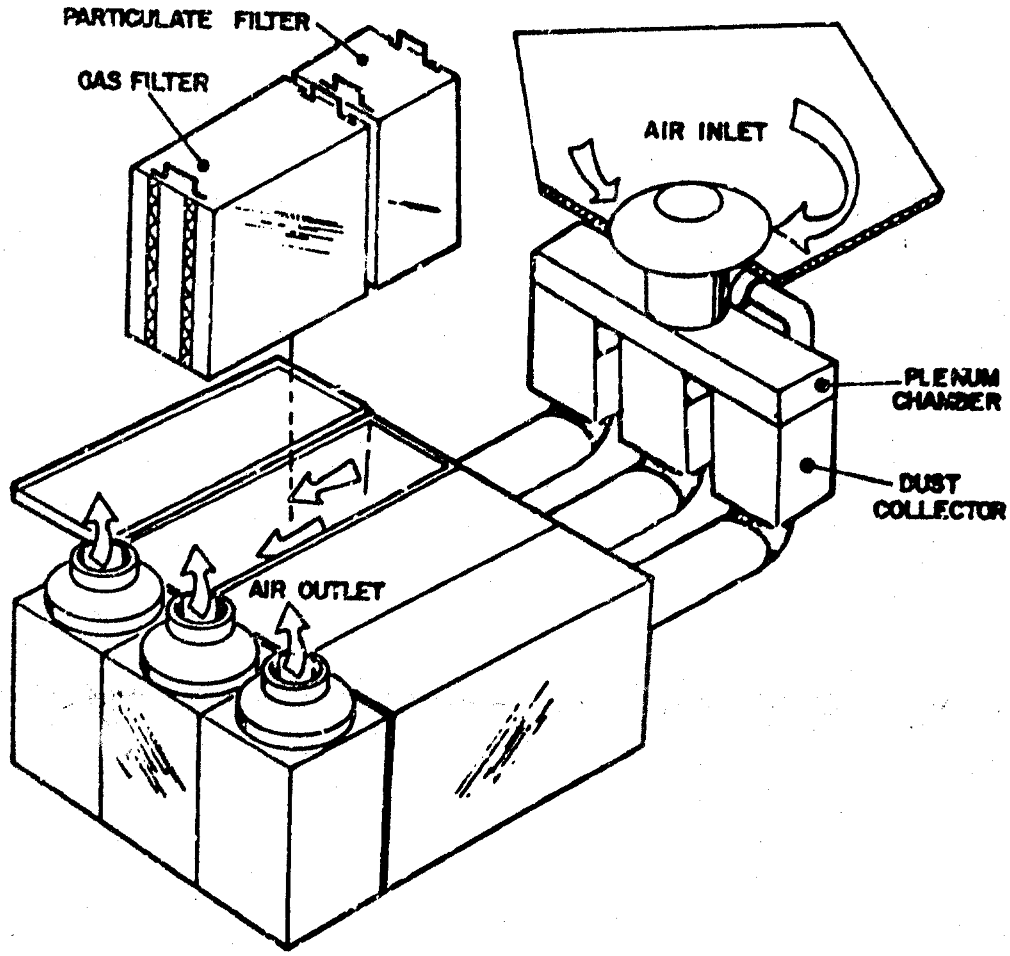
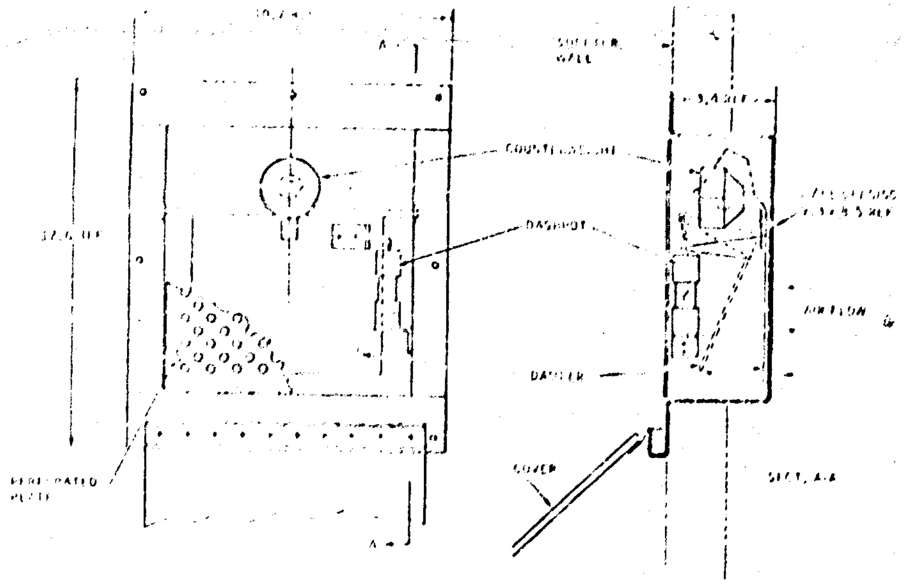
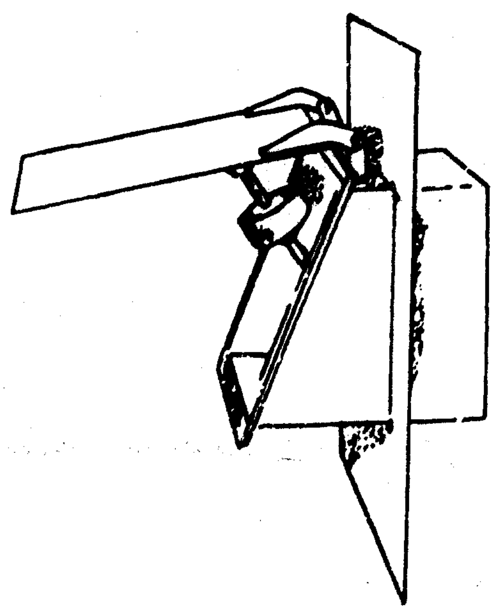


Figure 11-10. Parallel Arrangement of Three GPFU's[1]



(A) Drawing showing installation of shelter wall[5]



(B) Isometric View[1]

Figure 11-11. Antibackdraft Valves

surrounded by uncontaminated air so the main fan or air supply is located upstream from the filter, thus pressurizing the filter housing above the ambient air. Any leakage in the housing will result in air leaking out, rather than the contaminated air leaking into the housing, and possibly entering the shelter. The modular approach facilitates application of the unit to either push-through or pull-through configuration.

Typical arrangements of CBR systems are shown schematically in Figs. 11-12 and 11-13. As is true for many military air-conditioning installations, CB protective equipment may be mounted on trailers for storage, transport, and operation. If the trailer is used for remote mounting, it is necessary to run electrical lines and air ducts between the conditioned space and the remote CB protection unit. Fig. 11-14 illustrates a remote mounting.

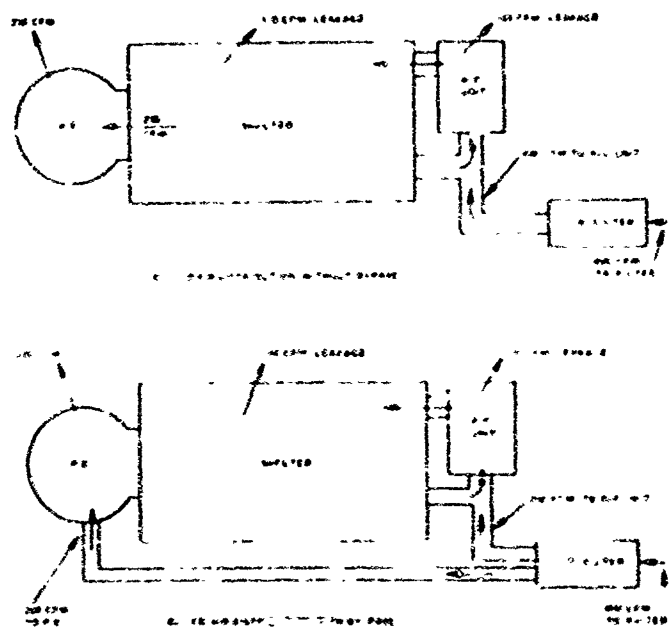


Figure 11-12. Typical CPE Air Distribution Methods[19]

REFERENCES

1. J. H. Scott, *Collective Protection for Vehicles, Vans and Shelters*, Phase I Final Report, Report No. 2, Donaldson Co., Inc., Minneapolis, Minn., February 1968 (AD-829 168).

2. *Collective Protection for Combat Field Structures*, Report No. 2951, Litton Systems, Inc., Applied Science Division, St. Paul, Minn., 9 March 1966 (AD-479 028).

3. *Collective Protection for Combat Field Structures*, Rep. 2711, Litton Systems, Inc., Applied Science Division, St. Paul, Minn., Jan. 1965 (AD-612 659).

4. *Collective Protection for Combat Field Structures*, Vol. 1, Report No. 2630, Litton Systems, Inc., Applied Science Division, St. Paul, Minn., 30 September 1964 (AD-609 805).

5. D. R. Walin, *Analysis and Design of CBR Protection for the AN/TSQ-47 System*, Tech. Documentary Rep. ESD-TDR-64-230, GDC-64-026, Gen. Dyn. Corp., San Diego, Calif., July 1964 (AD-603 100).

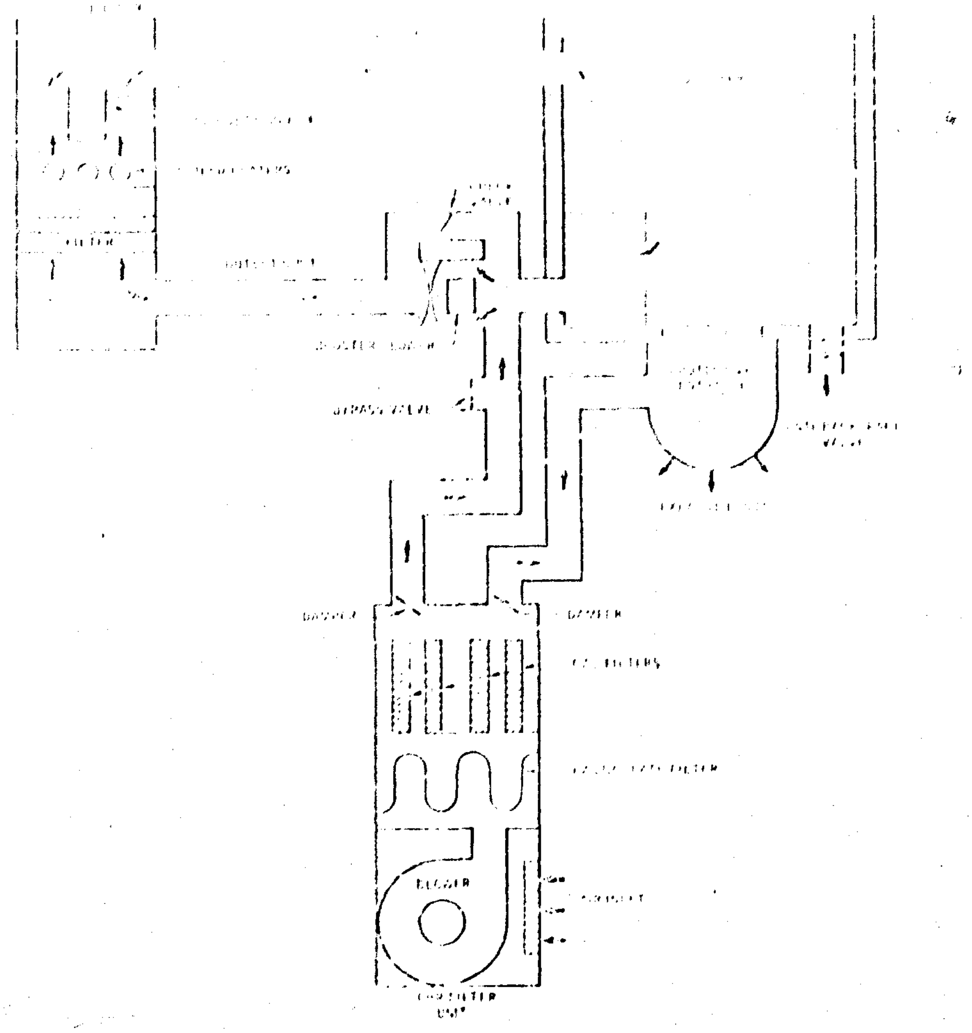


Figure 11-13. Schematic Drawing of Collective Protection System With Booster Blower[5]

6. R. D. Rivers, K. L. Westlin, and R. J. Boylan, *Collective Protection for Command Post Vehicles, M292 Design Study Report*, Amer. Air Filter Co., Inc., Louisville, Kentucky, 4 May 1965 (AD-462 507).

7. *Analysis of Cooling-Heating-Collective Protection for AN/GSM-44 System*, FR-64-11-342, Hughes Aircraft Company, Fullerton, Calif., December 1964 (AD-609 406). (This report is Appendix A of "Military Characteristics for Collective Protection for Military Transport Vehicles.")

8. *Feasibility and Design Study for Collec-*

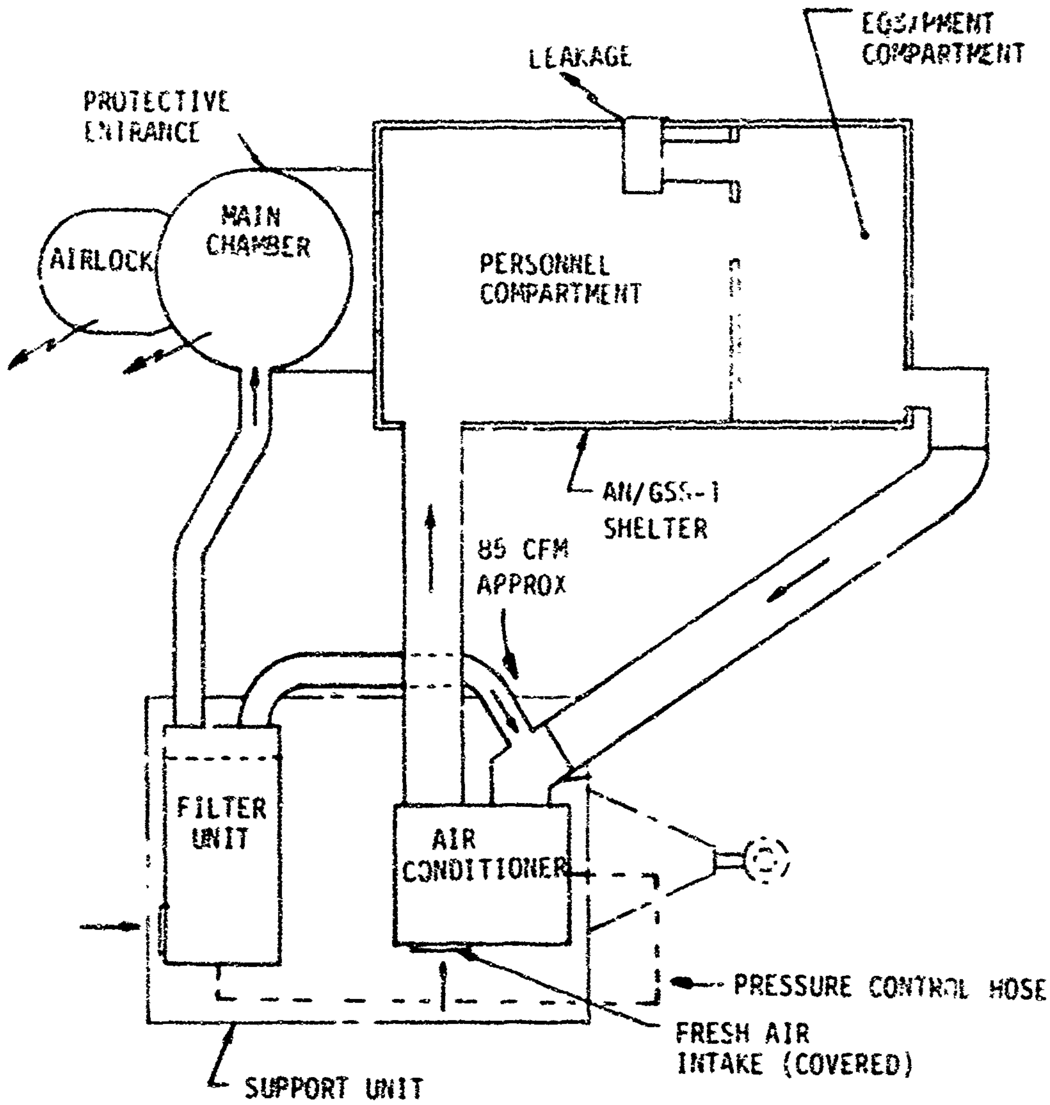


Figure 11-14. Schematic Drawing of Shelter Collective Protection System With Air Conditioner and Filter Unit Mounted on Trailer[10]

tive Protection Equipment for the AN/MSG-4 System, Study Report FD 62-75 Hughes Aircraft Company, Fullerton, Calif., 15 March 1962 (AD-274 245).

9. *Feasibility Study of Collective Protection for Radio Terminal Set AN/MRC-69(V) and Radio Terminal Set AN/MRC-74*, Hughes Aircraft Company, Fullerton, California, February 1965 (AD-458 152).

10. N. P. Oldson and R. J. Zablodil, *Collective Protector Design and Development*, Technical Note N-783, U. S. Naval Civil Engineering Lab. Port Hueneme, Calif., November 1965 (AD-625 402).

11. W. Gooley, Jr. and R. A. McCullough, *Report for Engineering Test of Collective Protection Unit for Combat Vehicle, Mechanized Infantry XM701* Report DPGR E546, Dugway Proving Ground.

Dugway, Utah, March 1966 (AD-482 623).

12. P. W. Klotz, *Tests of the Modified Chemical and Biological Flightline Taxis*, Report ADTC-TR-68-4, Armament Development and Test Center, Eglin Air Force Base, Florida, August 1968 (AD-840 276).

13. J. H. Scott, *Collective Protection for Vehicles, Vans and Shelters*, Report No. 3, Donaldson Co., Inc., Minneapolis, Minn., June 1968 (AD-837 997).

14. J. H. Scott, *Collective Protection for Vehicles, Vans and Shelters*, Report No. 4, Donaldson Co., Inc., Minneapolis, Minn., September 1968 (AD-844 172).

15. Human Engineering Laboratories Standard S-2-64A, *Human Factors Engineering Design Standard for Vehicle Fighting Compartments*, Aberdeen Proving Ground, Md., June 1968.

16. C. A. Hafer, and D. J. Skinner, *Definition of the Dust Environment for Purposes of Gas Turbine Ingestion Studies, Phase I*, Report No. SW-RI-EE-387, Southwest Research Institute, Dept. of Automotive Research, San Antonio, Texas, 26 Oct. 1960 (AD-472 676).

17. *Design and Development of a Collective Protection System for the Main Battle Tank*, Donaldson Co., Inc., Minneapolis, Minn., Jan. 1964 (AD-429 171).

18. Univ. of Pittsburgh Army Materiel Res. Staff, *Development of Collective Protection for Tentage and Field Shelters*, Technical Information Report 21-4-2B1, University of Pittsburgh, Pa., April 1964 (AD-444 298).

19. *Feasibility Study, Collective Protection Equipment for RTS, MITE, and AN/GSM-44 Shelters*, Report FR-64-11-7, Hughes Aircraft Company, Ground Systems, Fullerton, California, 5 Feb. 1964 (AD-431 306).

20. J. C. Groff, *Development of Collective Protection/Climate Control Support Unit and Collective Protection System for AN/GSS-1 Radar Surveillance Central*, Summary Report FR-66-11-27, Hughes Aircraft Co., Fullerton, Calif., December 1967 (AD-477 512).

APPENDIX A

FUNDAMENTALS

A-1 THE PSYCHROMETRIC CHART

The interrelationships between the thermodynamic quantities of the mixture of air and water vapor are represented in a concise form on the psychrometric chart. The U.S. Army Psychrometric Chart, Fig. A-1, gives the following quantities*:

(1) *Dry Bulb Temperature*, °F

(2) *Wet Bulb Temperature*, °F

(3) *Enthalpy*, Btu per pound of dry air. (The chart gives the enthalpy in the air and its associated moisture, relative to dry air at 0°F, expressed as Btu per pound of dry air.)

(4) *Relative Humidity*

(5) *Humidity Ratio*, grains or pounds of moisture per pound of dry air. (The dry bulb temperature and the humidity ratio form the linear orthogonal coordinate system of the psychrometric chart.)

(6) *Specific Volume*, cubic feet per pound of dry air

(7) *Effective Temperature (ET)*, °F.

If any two of the above quantities are specified, all the other quantities can be read from the psychrometric chart. In particular, for a change between given initial and final conditions, the amount of energy involved is given by the difference in the corresponding enthalpies.

*See Glossary for definitions.

A-2 OVERALL HEAT TRANSFER COEFFICIENT

The overall heat transfer coefficient, or *U factor*, of a wall can be derived from the expression

$$U = \frac{1}{\Sigma R + \frac{1}{f_i} + \frac{1}{f_o}}, \text{Btu/(hr-ft}^2\text{-°F)} \qquad \text{(A-1)}$$

where ΣR represents the sum of the thermal resistances of all layers of material (including air spaces) composing the wall, and f_i and f_o are the air film conductances at the inner and outer surfaces, respectively. Typical values of film conductances are (Ref. 4, Ch. 26):

f_i = 2 Btu/(hr-ft²-°F)

f_o = 4 Btu/(hr-ft²-°F), for an outside air velocity of 7.5 mph

f_o = 6 Btu/(hr-ft²-°F), for an outside air velocity of 15 mph.

With the smaller value of f_o, we have

$$U = \frac{1}{\Sigma R + 0.75}$$

and with the larger value of f_o, we have

$$U = \frac{1}{\Sigma R + 0.67}$$

Thus, considering that the contribution of ΣR is dominant, a practical formula for typical outside design conditions is

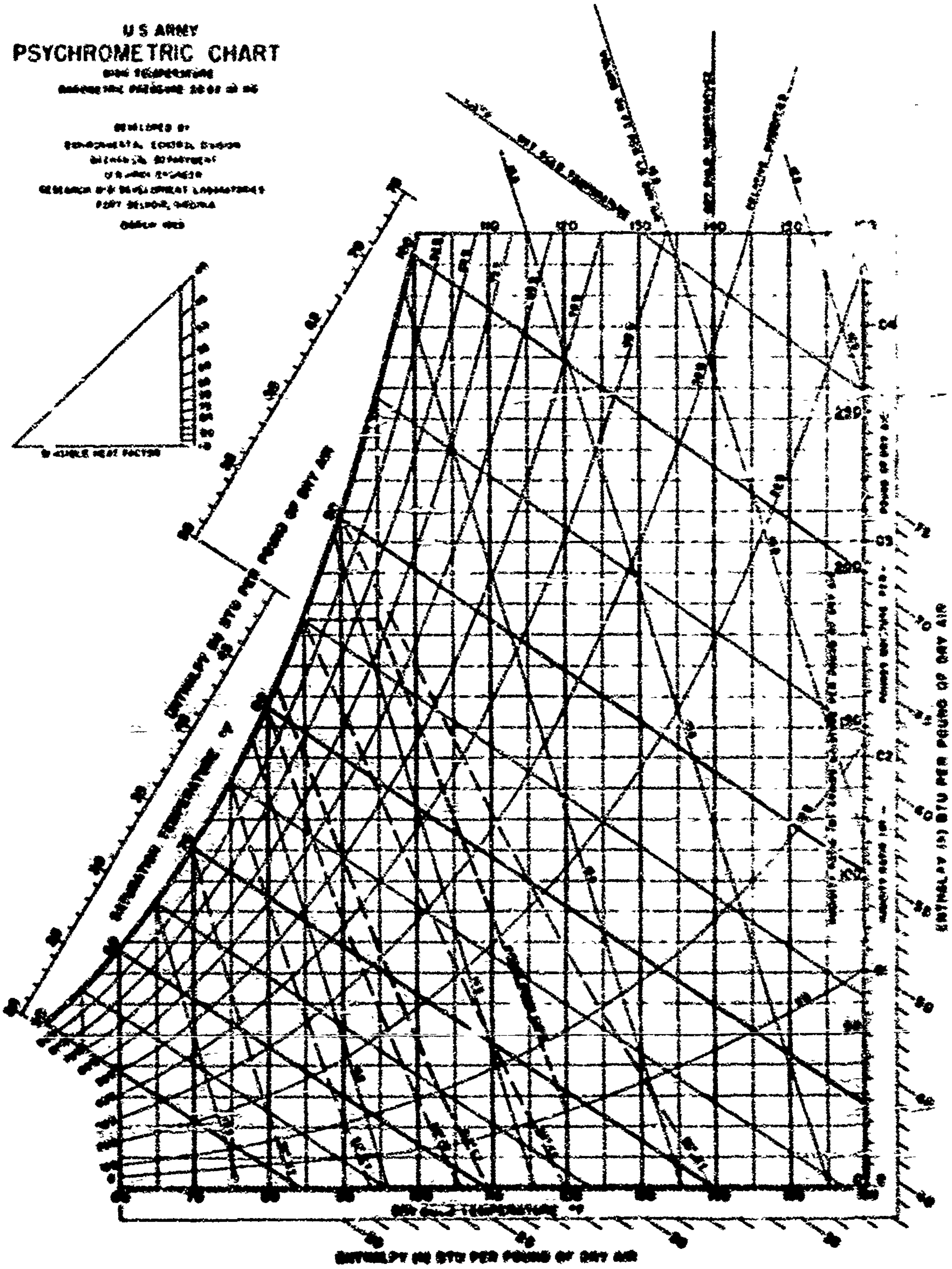


Figure A-1. U.S. Army Psychrometric Chart

$$U = \frac{1}{\Sigma R + 0.7}, \text{ Btu/(hr-ft}^2\text{-°F)} \qquad \text{(A-2)}$$

provided R has the reciprocal units of U.

The average overall heat transfer coefficient of an enclosure can be determined with a test chamber in which it is possible to control the temperature. The van, shelter, or other enclosure to be tested is placed inside the test chamber. Then a heat source which generates heat at a known rate is placed inside the enclosure so that heat is distributed uniformly within it. When equilibrium conditions are established, the *U factor* is given by

$$U = \frac{q}{A(t_i - t_o)}, \text{ Btu/(hr-ft}^2\text{-°F)} \qquad \text{(A-3)}$$

where

A = total surface area of enclosure, ft^2

q = rate at which heat is generated inside the enclosure, Btu/hr

t_i = average temperature inside the enclosure, °F

t_o = average temperature outside the enclosure, °F

Although this procedure does not accurately simulate the outdoor conditions (mainly the wind velocity and radiation factors) the value obtained is suitable for applications within the scope of this handbook.

A-3 MEASURES OF RELIABILITY

A measure of the reliability of a device is the mean-time-between-failures (MTBF). It depends on the failure rate of each of the components in a system. To determine the MTBF, one must start by preparing a model showing the relation of all the functional components in the system. Assuming that component failures are mutually independent and that all components must perform satisfactorily for the system to perform satisfactorily, it follows that the failure rate of the system is the sum of the failure rates of all its components. Then

$$MTBF = \frac{1}{\text{Sum of Individual Failure Rates}} \qquad \text{(A-4)}$$

An example of a reliability analysis for three alternative environmental control systems is given in Appendix 0 of Ref. 1. Additional information on the assessment of system reliability can be found in Refs. 2 and 3. Ref. 4 provides failure-rate data on many components of military hardware.

Reliability R is defined by the formula

$$R = \exp[-t/MTBF] \qquad \text{(A-5)}$$

where

t = mission time

$MTBF$ = mean-time-between-failures

The reliability of a unit with a given $MTBF$ is the probability that the unit will operate without failure for a period t. Values of $MTBF$ can be established for a component by records of its performance while in use or by reliability demonstration tests. For a given $MTBF$, the reliability decreases if the mission time is increased.

REFERENCES

1. C. A. Hagberg, *Collective Protection for Combat Field Structures, Vol. II*, Report No. 3000, Litton Systems, Inc., Minneapolis, Minnesota, Sept. 1966.
2. Astro Reliability Corp., *Reliability Assessment Handbook*, 16 July 1961 – 6 January 1962.

This report is an astute re-examination of the whole gamut of published technology of reliability assessments of electronic and electromechanical systems.*

3. *Reliability Document LMSC 447458*, Lockheed Missile and Space Company, Sunnyvale, Calif., 6 June 1962.

   This document is a comprehensive presentation of techniques to be utilized in the assessment of system, component and part reliability considerations encountered during design, manufacture and test.*

4. Bureau of Naval Weapons (BuWeps), *Failure Rate Data Handbook*, (FARADA) SP63-470.

   FARADA is a BuWeps-sponsored service to provide reliability design data to prime contractors engaged in the design, development, and production of hardware for various submarine, ship, aircraft, guided missile, satellite, and ground-support equipment programs. Military contractors and others participating in the program contribute failure rate data from information obtained in their programs. The transmitted data are revised periodically as new information becomes available. There are about 124 contributing sources (none identified by name) who supply data in two categories: electrical and electronic components and mechanical, hydraulic, pneumatic, pyrotechnic, and miscellaneous components. Each failure rate presented is identified as to source and the data from which it was computed.*

*This explanatory note was obtained from Appendix C of Ref. 1.

APPENDIX B

DESIGN CRITERIA

B-1 CLIMATIC DESIGN CRITERIA

The policy regarding climatic design criteria for Army materiel is given in Ref. 1:

"1-2. Policy. a. Climatic considerations will be included in RDTE [Research, Development, Test, and Evaluation] of Army Materiel to provide safe and effective materiel for areas of intended use (operation, and storage and transit). The Antarctic continent is excluded from consideration as an area of intended use. b. Standard general purpose materiel will be designed for safe and effective use in the intermediate and wet climatic categories (Categories 1,2,5, and 6 defined in Chapter 2). Materiel for use in other climatic categories will be provided by designing: (1) standard materiel capable of such use; (2) special materiel exclusively for such use; or (3) modification kits which adapt new standard materiel or previously type-classified standard materiel. The approach chosen will be that which provides satisfactory results in the most economical manner, considering extent of deployment in each area of intended use, the development state of the art, and the time required for development. For example, if certain materiel is to be used only in extreme cold conditions, the second approach above would be selected in most cases."

Ref. 1 defines the various climatic categories by specifying the conditions of air and water temperature, solar radiation, water vapor, precipitation, snow and icing phenomena, winds, atmospheric pressure, and blowing sand and dust. The operational conditions of temperature, humidity and solar radiation for the *intermediate* and *wet* climatic categories, which are used in most applications, are quoted in the paragraphs which follow.

Category 1, wet-warm. "Persistence of relative humidity above 95 percent in association with temperature nearly constant at 75°F occur for periods of a day or more."

Category 2, wet-hot. "Four continuous hours with an ambient temperature (4-6 ft above the ground) of 95°F, a maximum ground surface temperature of 130°F, maximum solar radiation (horizontal surface), at a rate of 360 Btu/ft^2/hr for not more than 4 hr, a windspeed less than 5 knots concurrent with the high temperatures, and relative humidity of 74 percent concurrent with the high temperatures."

Category 5, intermediate hot-dry. "Four hours with an ambient air temperature (4-6 ft above the ground) above 105°F with an extreme temperature of 110°F for not more than 1 hr, a maximum ground surface temperature of 130°F, solar radiation (horizontal surface) at a rate of 360 Btu/ft^2/hr for not more than 4 hr, and a windspeed between 5 and 10 knots during period with temperature above 105°F. For elevations of 3,000 ft to 10,000 ft, the ground surface temperature and wind remain the same, but ambient air temperatures decrease 5°F per 1,000 ft and solar radiation increases at a rate of 4 Btu/ft^2/hr per 1,000 ft."

Category 6, intermediate cold. "Six continuous hours with an ambient air temperatures (4-6 ft above the ground) of −25°F, a minimum ground surface temperature −35°F, windspeed less than 10 knots, negligible solar

radiation (horizontal surface), and humidity tending toward saturation. Infrequently, windspeeds greater than 10 knots may be associated with temperatures of −25°F."

B-2 ALLOWABLE CARBON MONOXIDE CONCENTRATIONS

In accordance with Ref. 2, carbon monoxide concentrations should not exceed the average values for the intervals indicated in Table B-1.

TABLE B-1

MAXIMUM ALLOWABLE CONCENTRATIONS OF CARBON MONOXIDE

Time Interval	CO Concentration, %
10 sec	0.50
20 sec	0.24
40 sec	0.12
1 min	0.08
3 min	0.03
5 min	0.02
60 min	0.01
More than 60 min	0.005

B-3 NOISE LEVEL SPECIFICATIONS

The maximum noise level permitted in personnel-occupied space of equipment designed, developed, or procured by the Army Materiel Command and the testing requirements for determining conformance to the permitted levels are established by HEL Standard S-2-64A[3]. This standard specifies that equipment for operating, training, or maintenance tasks shall not require personnel to be exposed to steady noise levels exceeding those given in Table B-2. Where continuous person-to-person (nonelectrically aided) communication of information is a system requirement, the steady noise levels should not exceed those given in Table B-3. Noise reduction may not be accomplished by specifying mandatory use of ear protective devices except to avoid prohibitive cost or degradation of system effectiveness (as determined by the procuring activity).

TABLE B-2

MAXIMUM STEADY STATE NOISE LEVEL FOR ARMY MATERIEL COMMAND EQUIPMENT

A. Commercial Frequencies ASA Z24.10-1953[5]

Octave Band Limits, Hz	Center Frequency, Hz	Noise Level*, dB
37.5 – 75	53	120
75 – 150	106	115
150 – 300	212	109
300 – 600	425	101
600 – 1200	850	93
1200 – 2400	1700	89
2400 – 4800	3400	88
4800 – 9600	6800	91

B. Preferred Frequencies ASA S1.6-1960[6]

Octave Band Limits, Hz	Center Frequency, Hz	Noise Level*, dB
44 – 87	63	119
87 – 175	125	114
175 – 350	250	107
350 – 700	500	98
700 – 1400	1000	91
1400 – 2800	2000	89
2800 – 5600	4000	88
5600 – 11200	8000	91

*Reference level is 0.0002 microbar.

TABLE B-3

MAXIMUM STEADY STATE NOISE LEVEL FOR NONELECTRICALLY AIDED PERSON-TO-PERSON COMMUNICATION

A. Commercial Frequencies ASA Z24.10-1953[5]

Octave Band Limits, Hz	Center Frequency, Hz	Noise Level*, dB
37.5 – 75	53	79
75 – 150	106	73
150 – 300	212	68
300 – 600	425	64
600 – 1200	850	62
1200 – 2400	1700	60
2400 – 4800	3400	58
4800 – 9600	6800	57

B. Preferred Frequencies ASA S1.6-1960[6]

Octave Band Limits, Hz	Center Frequency, Hz	Noise Level*, dB
44 – 87	63	77
87 – 175	125	72
175 – 350	250	67
350 – 700	500	63
700 – 1400	1000	61
1400 – 2800	2000	59
2800 – 5600	4000	58
5600 – 11200	8000	57

*Reference level is 0.0002 microbar.

Ref. 4 gives a practical example of a study to determine how much acoustical material is required in a shelter to comply with the requirements of Table B-3A.

B-4 EFFECT OF NOISE ON VERBAL COMMUNICATION

The effect of noise on verbal communication can be expressed in terms of the Speech Interference Level. In accordance with Ref. 2:

"The speech-interference level (SIL) describes how effectively noise masks speech. SIL is defined as the average (in dB) of the masking noise's sound levels in three octave bands: 600 to 1200, 1200 to 2400, and 2400 to 4800 Hertz (Hz). Sometimes speech interference can be predicted better by also averaging in the 300-600 Hz band if it is 10 dB or more louder than the 600-1200 Hz band. The SIL cannot be used if the masking noise has intense low-frequency components or if it is concentrated in a narrow band. The distance and voice level which will permit reliable conversation (70 percent monosyllabic word intelligibility) for direct person-to-person (nonelectrically aided) communications at various SIL without lip reading is shown in Figure [B-1]."

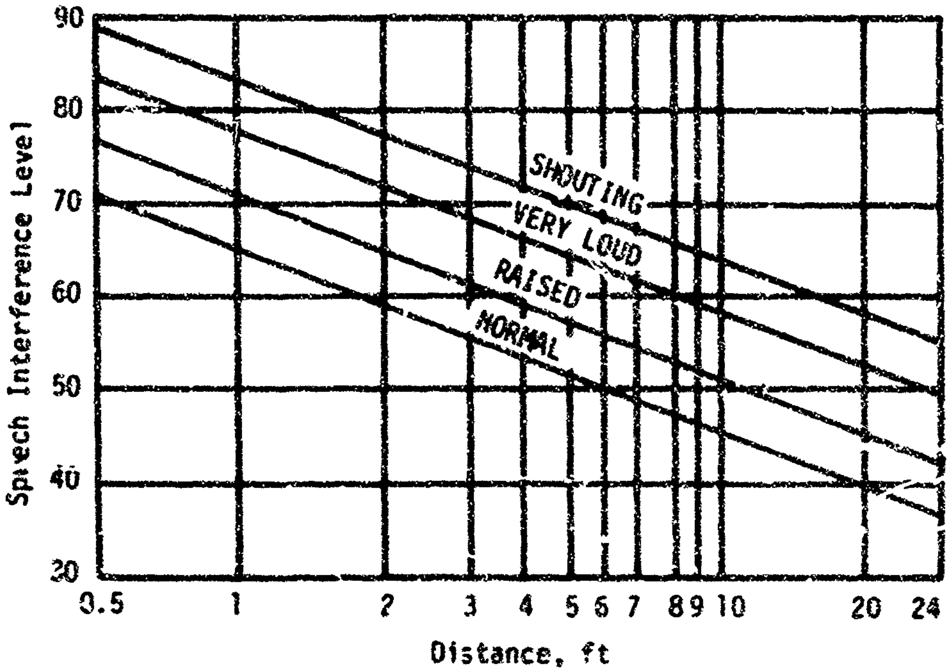


Figure B-1. Effect of Noise, Separation, and Voice Level on Person-to-person Communication

REFERENCES

1. AR 70-38, *Research, Development, Test, and Evaluation of Materiel for Extreme Climatic Conditions*, 5 May 1969.

2. HEL Standard S-6-68, *Human Factors Engineering Design Standard for Communication Systems and Related Equipment*, U.S. Army Human Engineering Laboratories, Aberdeen Proving Ground, Md., Dec. 1968.

3. HEL Standard S-1-63B, *Maximum Noise Level for Army Materiel Command Equipment*, U.S. Army Human Engineering Laboratories, Aberdeen Proving Ground, Md., June 1965.

4. H.H. Holland, Jr., *Noise Attenuating Materials in an S-141/G Shelter*, Tech. Note 1-68, U.S. Army Human Engineering Laboratories, Aberdeen Proving Ground, Md., Jan. 1968 (AD-666 207).

5. American Standards Assn., ASA Z24.10-1958, *Octave-Band Filter Set for the Analysis of Noise and Other Sounds*, ASA, New York, N.Y.

6. American Standards Assn., ASA S1.6-1960, *Preferred Frequencies for Acoustical Measurements*, ASA, New York, N.Y.

APPENDIX C

DESIGN PROCEDURES

C-1 DETERMINATION OF ENVIRONMENTAL CONTROL REQUIREMENTS

C-1.1 OUTLINE OF PROCEDURE

While it is outside the scope of this handbook to give a thorough account of the calculation of environmental control requirements, some information on the subject is included in this Appendix. This paragraph gives an outline of the procedure including consideration of factors which affect the design of an environmental control system; following paragraphs give practical examples of design calculations.

The following is an outline of a procedure for determining the performance requirements in designing an environmental control system for a shelter:

(1) Calculate shelter wall heat transmission. This will require assumptions for the following parameters: geographic locations, shelter orientation, time of day, wind velocity and direction, outside temperature, and desired shelter temperature.

(2) Calculate heat transfer through walls of air ducts which are external to the shelter.

(3) Summarize total heat loads. The loads calculated in Items (1) and (2) are to be added to the personnel heat loads and the heat loads generated by equipment within the shelter. The summation of the heat loads indicates the quantity of heat which must be removed from the shelter.

(4) Determine the pressure loss characteristics in an environmental control system in which fan driven air is used as the transfer media. An estimate of the pressure loss in the circulating system will permit determination of the static pressure which must be maintained at the entrance to the system. Factors to be considered in this estimate include ducting loss, shelter distribution loss, shelter leakage, and heating/cooling equipment loss. Determine characteristics of a fan required to overcome the pressure loss while maintaining the required air flow rate.

C-1.2 LATENT HEAT LOAD CONSIDERATIONS

The latent heat load is of interest only during the portion of the environmental control operation when cooling is required. The principal sources of latent heat load in a shelter are: moisture from personnel respiration and perspiration, moisture from materials within the shelter, moisture from processes (e.g., photographic processing and laboratory baths) within the shelter, and moisture admitted with outside air used for ventilation.

Although an estimate may be made of the latent heat load before selecting air conditioning equipment for shelter environmental control, there is little one can do to accommodate this load. The packaged air conditioners of the type used for portable shelters have the capability of removing a fixed ratio of moisture to heat (latent heat/sensible heat) in a given operating state. The latent heat factor, or ratio of latent heat to sensible heat removed by the equipment, varies from 0.15 to 0.35. Evaporator coil design affects this ratio in a predictable manner; the longer the air is in contact with the cooling coil surfaces, the greater the quantity of moisture removed from the air. Thus, low air velocities through

deep coils tend to increase moisture removal, which is equivalent to removal of latent heat

The example given in par. C-4, Appendix C, indicates how to take the latent heat load into account when selecting an air conditioner.

C-1.3 ENVIRONMENTAL REQUIREMENTS FOR EQUIPMENT AND ACTIVITIES

In addition to accommodating personnel, the environmental control system must accommodate equipment and processes conducted in the controlled space. Conditions of temperature and humidity which are required for typical operations are listed in Table C-1.

C-1.4 PERFORMANCE VARIATION WITH ALTITUDE

The effects of altitude on environmental control systems for mobile shelters should be considered when designing the installation. Although specific information is seldom published concerning equipment ratings at high altitudes, application of engineering judgment will enable the designer to make an estimate of the adequacy of his design. Ref. 1 indicates how the high altitude performance of air-conditioning units can be estimated. Examples of the effect of altitude on the performance on some common components of environmental control systems are:

(1) *Motors.* Reduced air density at high altitudes has the effect of lowering the heat transfer rate while the motor is in operation, thus suggesting derating the power output of the motor. Motors should be derated by a factor approximately equal to the air density ratio. For example the density of air at 5,000 ft is 0.83 times that at sea level. Therefore, a motor with a rating of 10 hp at sea level for operation at 5,000 ft should be rated at about 8.3 hp.

(2) *Fans.* Contrary to intuition, the designer can expect fans driven by alternating current motors to provide approximately the same performance (in cfm) at high altitudes as at sea level.

(3) *Air-cooled Condensers.* Where the air cooled condenser is equipped with a motor-driven fan to move the air across the coils, the following would be the situation at high altitudes. An equal volume of air will move over the coils at any altitude, but that at the higher altitude will be less dense; therefore the mass flow rate is lower and the heat transfer rate will be reduced by a factor approximately equivalent to the air density ratio. The condenser must be derated by this ratio.

(4) *Heating Coils.* The derating required as previously noted for air-cooled condensers, may also be applied to those heating devices

TABLE C-1

TEMPERATURE AND HUMIDITY REQUIREMENTS FOR TYPICAL EQUIPMENT AND ACTIVITIES

Equipment or Activity	Temperature (Dry Bulb), °F	Relative Humidity, %
1. Electronic equipment, computers	65-80	20-65
2. Photographic processing and printing	70-80	45-50
3. Repair bench, electrical or electronic	65-80	20-65
4. Repair bench, small mechanisms	72-76	40-45
5. Chemical laboratory	65-80	20-65

which depend upon convection or forced air flow for heat transfer. The rate of heat transfer by radiation is considered to be independent of air density variations.

C-2 CALCULATION OF COOLING REQUIREMENTS

The following example of the procedure for calculating cooling loads was taken from Ref. 2. It serves to illustrate the required steps. A more detailed description of design calculations for both heating and cooling requirements is given in another example, in par. C-4, Appendix C.

A. *Design Conditions**

1. *Outside Design Ambient Temperature*. Army Regulation AR 70-38 establishes the maximum design ambient condition of 125°F DB.

2. *Inside Design Temperature*. When selecting an inside design temperature, it must first be determined whether the controlling factor is personnel or equipment. Once the controlling factor is determined, the inside design temperature should be based on the maximum allowable. For photographic processes, it may be 70°-75°F. For personnel, the temperature may be 70°-80°F and for electronic applications, 80°-100°F.

When designing for extreme outside ambient conditions, it is usually desirable to raise the inside design temperature not only to reduce the amount of cooling required, but also to make it more comfortable for personnel moving in and out of the shelter. A 15-degree difference is recommended.

3. *Ventilation Air*. The third design factor is the amount of ventilation air to be brought into the system. Excess ventilation air needlessly increases either the sensible cooling load, the latent cooling load or both.

The recommended ventilation air is 15 cfm per person, when moderately heavy smoking is anticipated.

By paying close attention to these three factors outside design ambient, inside design temperature, and ventilation air requirements the system designer can choose an air conditioner that is adequate but not oversized.

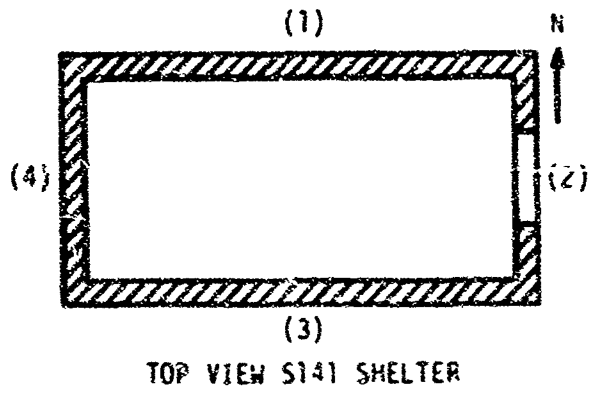
B. *Sample Problem*

To illustrate the selection procedure the following example is used. Assume that an S141 shelter (light frame construction) is to house two people and electrical equipment having a 3.16 kW rating. The shelter is to be located at 40 deg North latitude and the time for the combined maximum heat gains from the various sources is assumed to be 2 PM, August 24. Fig. C-1 shows the dimensions and location of the shelter.

C. *Solution*

The following symbols are used in the calculations.

C_{pa} = specific heat of air at constant pressure = 0.24 Btu/(lb°-F)



TOP VIEW S141 SHELTER

Dimensions: 142 in. L, 81 in. W, [illegible]

Exterior Color: Dark Green

Wall & Roof U-Factor: 0.35 Btu/(hr-ft^2-°F)

Design Ambient: 125 DB 80 WB

Indoor Design Temp.: 80 DB 67.5 WB

Figure C-1. Plan View of S141 Shelter

*With minor changes, the rest of this Appendix was taken from Ref. 2, applying the principles of Ref. 4.

L = latent heat of vaporization of water = 1054 Btu/lb

N = number of occupants

q_E = heat input from electrical equipment, Btu/hr

q_P = heat input from each van occupant, Btu/hr

q_P' = total heat input from van occupants, Btu/hr

q_f = heat input through floor, Btu/hr

q_r = heat input through roof, Btu/hr

q_v = ventilation air heat gain, Btu/hr

q_w = heat input through wall, Btu/hr

Q = ventilation air flow rate, cfm

$t_o(DB)$ = dry bulb temperature of outside air entering air conditioner, °F

$t_i(DB)$ = dry bulb temperature of air inside conditioned space, °F

Δt = $t_o(DB) - t_i(DB)$, °F

Equivalent Δt = Δt corrected to take solar radiation into account, °F

w_o = pounds of water vapor per pound of dry air in outside air

w_i = pounds of water vapor per pound of dry air inside conditioned space

γ_o = specific weight of air at standard conditions (70°F, 1 atm) = 0.075 lb/ft³

Subscripts

L = latent

s = sensible

The cooling load calculations are as follows:

1. *Transmission and Solar Sensible Heat Gains* q_{sw} *through walls and* q_{sr} *through roof*

q_{sw} = *Area* (ft^2) x *U-factor* x *Equivalent* Δt

a. *Wall (1) facing North (Refer to Fig. C-1)*

q_{sw} = 82 (0.35) 12 = 340 Btu/hr

(Note: See Table C-2, or similar tables in Ref. 4, for equivalent temperature difference.)

b. *Wall (2) facing East*

q_{sw} = 46.5 (0.35) 14 = 230 Btu/hr

c. *Wall (3) facing South*

q_{sw} = 82 (0.35) 41 = 1180 Btu/hr

d. *Wall (4) facing West*

q_{sw} = 46.5 (0.35) 22 = 360 Btu/hr

e. *Roof*

q_{sr} = 80 (0.35) 64 = 1790 Btu/hr

(Note: See Table 3-38 of Ref. 3, or similar tables in Ref. 4, for equivalent temperature difference.)

$$\Sigma q_{sw} + q_{sr} = 340 + 230 + 1180 + 360 + 1790 = 3900 \text{ Btu/hr}$$

TABLE C-2

TOTAL EQUIVALENT TEMPERATURE DIFFERENTIALS FOR WALLS FOR APRIL 20 AND AUGUST 24*[3]

NORTH LATITUDE	SUN TIME A M 8 D	8 L	10 D	10 L	12 D	12 L	P M 2 D	2 L	4 D	4 L	6 D	6 L	8 D	8 L	10 D	10 L	12 D	12 L	SOUTH LATITUDE
	EXTERIOR COLOR D - DARK L - LIGHT																		
	FRAME																		
NE	19	9	21	11	14	11	14	12	16	14	16	16	12	12	8	8	4	4	SE
E	32	16	36	20	34	18	14	14	16	16	16	18	12	12	8	8	4	4	E
SE	10	10	31	21	34	22	28	19	19	16	16	16	12	12	8	8	4	4	NE
S	-2	-2	8	3	32	18	41	26	33	25	20	17	13	13	8	8	5	5	N
SW	-2	2	2	0	8	6	21	26	40	32	49	33	29	24	8	5	4	4	NW
W	-2	-2	2	2	6	8	22	14	42	30	50	36	54	34	10	13	4	8	W
NW	-2	-2	2	0	8	6	14	12	24	21	37	28	31	23	8	8	4	4	SW
(SHADE) N	-2	-2	0	0	6	6	12	12	16	16	14	14	10	10	6	6	5	2	S (SHADE)
	4" BRICK OR STONE VENEER + FRAME																		
NE	0	-2	21	11	18	10	17	8	14	12	16	6	14	14	12	12	8	8	SE
E	4	2	22	18	33	19	18	16	16	14	18	18	14	14	12	10	8	8	E
SE	5	0	26	14	25	21	31	20	21	17	16	18	14	14	12	10	9	8	NE
S	-2	-2	0	0	19	11	34	22	33	24	26	20	14	14	10	10	6	8	N
SW	3	6	2	0	4	4	15	10	36	26	42	30	40	28	12	10	9	8	NW
W	2	0	2	2	8	4	12	10	28	20	42	30	44	30	18	16	8	0	W
NW	-2	-2	0	0	4	4	10	3	14	14	29	22	32	24	13	12	8	8	SW
(SHADE) N	-2	-2	0	0	2	2	8	8	12	12	14	14	14	14	10	10	6	6	S (SHADE)
	8" HOLLOW TILE OR 8" CINDER BLOCK																		
NE	2	2	2	2	18	10	15	10	11	8	14	12	18	14	14	12	10	10	SE
E	6	4	16	8	28	14	28	16	22	14	14	12	16	14	16	12	12	10	E
SE	8	2	5	3	21	12	25	18	26	17	17	14	17	14	14	12	10	8	NE
S	2	3	3	3	6	3	18	11	24	20	35	21	24	18	15	12	11	8	N
SW	4	[illegible]	6	2	5	2	[illegible]	7	18	13	31	21	35	24	31	21	10	8	NW
W	6	4	6	4	6	4	8	6	18	16	20	16	44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
NW	2	2	2	2	3	2	5	4	10	8	14	12	22	19	20	22	11	10	SW
(SHADE) N	0	0	0	0	0	0	2	2	8	8	12	12	12	12	12	12	8	9	S (SHADE)
	8" BRICK OR 12" HOLLOW TILE OR 12" CINDER BLOCK																		
NE	4	4	4	4	10	4	15	9	14	9	11	8	12	10	12	12	11	10	SE
E	10	8	10	8	18	10	20	12	30	12	18	10	16	12	15	12	14	12	E
SE	11	7	9	7	9	7	18	14	23	18	20	13	15	12	15	12	15	13	NE
S	8	5	8	5	8	8	8	5	16	10	22	14	22	16	18	13	14	11	N
SW	11	7	9	7	9	7	11	7	13	9	15	10	24	13	29	19	24	17	NW
W	16	6	6	6	8	8	10	8	12	8	16	10	22	18	26	18	20	10	W
NW	4	4	4	4	4	4	5	4	7	6	15	8	12	10	17	15	19	15	SW
(SHADE) N	2	2	2	2	2	2	2	2	4	4	6	8	10	10	10	10	8	8	S (SHADE)
	12" BRICK																		
NE	9	9	9	7	9	8	9	8	11	6	12	7	12	7	11	8	11	8	SE
E	14	10	14	10	14	10	12	8	14	10	10	12	18	12	16	10	18	10	E
SE	13	8	13	9	13	9	13	9	13	9	15	11	18	13	19	13	18	10	N
S	12	9	12	10	19	7	10	7	10	7	13	7	18	10	10	13	17	11	NE
SW	13	8	12	9	13	9	13	9	13	9	13	11	13	11	12	11	17	13	NW
W	14	10	14	10	14	10	12	8	12	8	12	8	12	8	14	10	10	12	W
NW	9	8	9	7	9	8	5	6	9	8	9	8	8	[illegible]	11	8	11	8	SW
(SHADE) N	8	6	4	4	4	4	4	4	4	4	4	4	4	4	8	8	8	8	S (SHADE)
	8" CONCRETE OR STONE OR 6" OR 8" CONCRETE BLOCK																		
NE	7	9	8	4	9	4	8	4	11	8	15	11	17	13	19	11	11	8	SE
E	8	0	16	10	26	16	26	14	30	18	16	18	16	12	14	12	12	10	E
SE	9	4	9	7	21	14	23	16	22	18	17	18	15	12	18	13	13	11	N
S	9	3	[illegible]	3	6	3	18	10	23	18	25	17	19	18	14	11	12	8	NE
SW	9	4	[illegible]	4	9	4	11	6	10	13	27	20	29	19	27	20	13	11	NW
W	8	4	8	6	8	6	10	8	12	10	22	18	30	20	28	20	18	12	W
NW	5	4	5	3	5	4	6	6	8	8	13	11	20	15	21	16	9	8	SW
(SHADE) N	2	2	2	2	2	2	4	4	6	6	8	8	10	10	8	8	4	0	S (SHADE)
	12" CONCRETE OR STONE																		
NE	7	8	7	4	7	6	13	9	14	9	11	8	11	10	12	12	11	10	SE
E	12	8	10	8	12	8	20	12	20	14	18	12	4	12	[illegible]	12	18	12	E
SE	11	7	11	7	9	7	18	11	20	13	20	13	17	13	18	12	15	10	N
S	11	8	8	5	8	5	8	5	16	10	20	15	22	17	19	13	14	11	NE
SW	11	7	11	7	9	7	9	7	11	9	13	11	22	17	24	17	22	19	NW
W	12	8	10	8	10	8	12	8	13	8	14	10	18	[illegible]	[illegible]	16	24	18	W
NW	7	5	7	4	7	4	7	5	7	6	9	8	11	10	18	13	20	15	SW
(SHADE) N	2	2	3	2	2	3	2	2	6	4	8	8	9	9	10	10	8	8	S (SHADE)

*Table C-2 is for 40 deg latitude. It may be used for south latitude for February 20 and October 23.

2. *Transmission Heat Gain through Floor* q_{sf}.

$$q_{sf} = Area\,(ft^2) \times U\text{-}factor \times \Delta t$$

$$= 80\,(0.35)\,(125 - 80) = 1260 \text{ Btu/hr}$$

(Δt is assuming free air passage beneath shelter)

3. *Heat Gain of Ventilation Air—Sensible* q_{sv} *and latent* q_{Lv}.

a. *Ventilation rate:*

Q = No. of persons x ventilation rate (cfm) per person

$Q = 2 \times 15$

$Q = 30$ cfm

b. *Sensible heat gain:*

$$q_{sv} = C_{pa}\ \gamma_o\ (60\ Q)\ [t_o(DB) - t_i(DB)]$$

$$= 0.24 \times 0.075 \times 60 \times 30\,(125 - 80) = 1460 \text{ Btu/hr}$$

c. *Latent heat gain:*

$$q_{Lv} = L\,\gamma_o\,(60\,Q)\,(w_o - w_i)$$

$= 1054 \times 0.075 \times 60 \times 30\,(0.0118 - 0.0115)$ with values of w determined from Fig. A-1

$= 40$ Btu/hr

Note: No outside air infiltration gain is assumed.

4. *Heat Gains from Occupants—Sensible* q'_{sP} *and latent* q'_{LP}.

a. *Sensible Heat:*

Following Ref. 10, we will assume that the sensible heat loss from the skin is approximately 200 Btu/hr/person.

$$q'_{sP} = N \times q_{sP}$$

$$= 2 \times 200 = 400 \text{ Btu/hr}$$

b. *Latent Heat.*

The latent heat loss by a seated male doing very light work is 200 Btu/hr/person.

$$q'_{LP} = N \times q_{LP}$$

$$= 2 \times 200 = 400 \text{ Btu/hr}$$

5. *Equipment Heat Gains (including lights)* q_E:

$$q_{sE} = \text{Wattage rating} \times 3.4\ (\text{Btu/hr})/\text{watt}$$

$$= 3160 \times 3.4 = 10{,}740 \text{ Btu/hr}$$

6. *Summary of Heat Gains* Σq_i:

	Sensible, Btu/hr	*Latent, Btu/hr*
a. Transmission and solar (walls and roof)	3900	
b. Transmission (floor)	1260	
c. Ventilation	1460	40
d. Occupants	400	400
e. Equipment	10,740	
Total	17,760	440

The following paragraph, par. C-3, gives an outline of the procedure for selecting an air conditioner to meet the above requirements. Another example of the calculation of heating and cooling loads is given in par. C-4, Appendix C.

C-3 EXAMPLE OF AIR CONDITIONER SELECTION

In this paragraph, we take the data on cooling load computation given in the par.

C-2 and show how to select an air conditioner.

We have:

(1) Ambient air temperatures:

$t_a(DB) = 125°F$

$t_a(WB) = 80°F$

(2) Conditioned air space temperature:

$t_i(DB) = 80°F$

$t_i(WB) = 67.5°F$

(3) Outside ventilation air flow rate:

$Q = 30$ cfm

(4) Rate of sensible heat gain:

$q_s = 17{,}760$ Btu/hr

(5) Rate of latent heat gain:

$q_L = 440$ Btu/hr

From the given data we find that the total cooling load is

$q = q_s + q_L = 18{,}200$ Btu/hr

(6) Sensible heat ratio:

$SHR = q_s/q = 0.98.$

To proceed with the example, we will use equipment capacity and performance tables (C-3 through C-7) taken from Ref. 10. Since the sensible heat ratio is nearly 1.0, we can use Table C-3 to make a tentative choice of air conditioner. Table C-4 can be used when the sensible heat ratio is substantially lower than 1.0, but Table C-3 always yields a conservative choice. From Table C-3, we see that the 400-Hz unit with a nominal capacity of 18,000 Btu/hr provides a cooling capacity of 18,300 Btu/hr when the temperature of the air entering the condenser is 125°F DB and the temperature of the conditioned air returning to the unit is 80°F DB, with SHR = 1.0. For accurate selection, however, it is necessary to compute the actual temperature of the conditioned air entering the unit. From Table C-7, we find that the free air delivery rate is 710 cfm. Since the rate of outside ventilation is 30 cfm, this leaves 680 cfm as the rate at which conditioned air enters the unit. Computing the calorimetric average temperature, $(30 \times 125 + 680 \times 80)/710$, we find that the dry-bulb temperature of the mixture will be 82°F. Returning to Table C-3 and interpolating for an entering cooled air temperature of 82°F DB, we find the actual capacity to be 18,820 Btu/hr, which is more than adequate for the application.

If supply or return air ducts are used, the

TABLE C-3

COMPACT-UNIT COOLING CAPACITIES (BTU/HR) AT 1.0 SENSIBLE HEAT RATIO AND FREE DELIVERY

NOMINAL COOLING CAPACITY, Btu/hr	60 Hz POWER SUPPLY														
	6000			9000			18000			36000			60000		
OUTSIDE AIR TEMPERATURE ENTERING CONDENSER, °F	95	110	125	95	110	125	95	110	125	95	110	125	95	110	125
COOLING AIR DRY BULB TEMPERATURE ENTERING UNIT, °F 70	6800	6200	5500	7500	8400	7400	18700	17000	15300	35600	37200	28900	54500	51100	45900
75	7400	6700	6000	10200	9100	8300	20100	18400	16400	38300	35000	31500	60700	55500	50000
80	8000	7200	6500	10900	9800	8700	21500	19800	18000	41000	37600	34200	65000	59600	54200
85	8500	7700	7000	11500	10400	9300	22800	21000	19300	43500	40200	36900	69200	63700	58500
90	9000	8200	7500	12100	11100	10000	24000	22400	20500	45900	42700	39800	72900	67800	62900
95	9400	8700	7900	12600	11700	10600	25100	23600	21800	48000	45200	42500	76300	72000	67400
100	9800	9100	8300	13200	12300	11300	26100	24800	23100	50000	47600	45100	79600	75700	71500

NOMINAL COOLING CAPACITY, Btu/hr	400 Hz CYCLE POWER SUPPLY														
	6000			9000			18000			36000			60000		
OUTSIDE AIR TEMPERATURE ENTERING CONDENSER, °F	95	110	125	95	110	125	95	110	125	95	110	125	95	110	125
COOLING AIR DRY BULB TEMPERATURE ENTERING UNIT, °F 70	6900	6200	5500	9600	8500	7500	19000	17300	15600	39100	35500	32000	60000	54500	48700
75	7500	6800	6000	10300	9300	8200	20500	18800	16900	42000	38300	34700	64200	58500	52900
80	8000	7300	6500	11000	10000	8800	22000	20200	18300	44600	41100	37600	68500	63000	57400
85	8500	7800	7000	11700	10700	9500	23300	21500	19600	47300	43900	40400	72800	67300	61800
90	9000	8200	7500	12400	11300	10200	24600	22800	20800	49900	46500	43200	76600	71800	66400
95	9400	8700	8000	13000	12000	10900	25600	24000	22200	52200	49200	46100	80300	75700	71100
100	9800	9100	8400	13500	12500	11300	26800	25300	23500	54500	51900	49100	83700	80000	75900

(Courtesy of Trane Company)

TABLE C-4
COMPACT-UNIT COOLING CAPACITIES AND SHR AT NOMINAL MILITARY CONDITIONED AIR DESIGN CONDITIONS
(50% Relative Humidity) Free Delivery

NOMINAL COOLING CAPACITY, Btu/hr		60 Hz POWER SUPPLY														
		6000			9000			18000			36000			60000		
OUTSIDE AIR TEMPERATURE ENTERING CONDENSER		95	110	125	95	110	125	95	110	125	95	110	125	95	110	125
EVAPORATOR ENTERING AIR	73/59 SHR	8000 .71	7100 .74	6100 .78	11100 .69	9600 .73	8200 .77	21900 .71	19400 .75	17000 .80	41800 .71	36700 .74	31900 .77	66500 .71	58300 .74	50800 .77
DRY BULB/WET BULB AND	80/67 SHR	9300 .67	8200 .69	7200 .71	12700 .66	11100 .68	9600 .70	25000 .67	22400 .69	19500 .71	47600 .67	42600 .69	37700 .71	75800 .67	67400 .69	59900 .71
SENSIBLE HEAT RATIO	90/75 SHR	10800 .59	9700 .62	8600 .64	14600 .58	13100 .61	11400 .64	29000 .60	26300 .62	23500 .65	55200 .60	50300 .62	45500 .65	87900 .59	79800 .61	72200 .64
NOMINAL COOLING CAPACITY, Btu/hr		400 Hz POWER SUPPLY														
		6000			9000			18000			36000			60000		
OUTSIDE AIR TEMPERATURE ENTERING CONDENSER		95	110	125	95	110	125	95	110	125	95	110	125	95	110	125
EVAPORATOR ENTERING AIR	73/59 SHR	8100 .75	7100 .77	6100 .80	11200 .70	9700 .74	8300 .79	22300 .73	19800 .77	17300 .81	45900 .70	40500 .73	35400 .77	70400 .74	62100 .77	54000 .80
DRY BULB/WET BULB AND	80/67 SHR	9300 .68	8200 .70	7200 .73	12900 .64	11300 .68	9800 .72	25500 .67	22800 .70	20200 .74	52000 .64	46500 [illegible]	41500 .71	79900 .67	71400 .70	63400 .73
SENSIBLE HEAT RATIO	SHR 90/75	10800 .60	9700 .63	8600 .66	14900 .58	13300 .61	11700 .64	29600 .60	26800 .63	23900 .66	60200 .59	54700 .62	49700 .64	92400 .62	84000 .64	76100 .66

(Courtesy of Trane Company)

TABLE C-5
COOLING CORRECTION FACTORS

(Apply to Table C-3 Cooling Capacities for CFM other than Standard at 1.0 Sensible Heat Ratio.)

PERCENT LESS CFM COMPARED TO RATED QUANTITY	Rated	-10	20	-30	-40
COOLING CAPACITY MULTIPLIER	1.00	.97	.93	.87	.80

(Courtesy of Trane Company)

TABLE C-6
COOLING AND SHR CORRECTION FACTORS

(Apply to Table C 4 Cooling Capacities for CFM other than Standard.)

PER COMPARED TO RATED QUANTITY	Rated	-10	20	-30	40
COOLING CAPACITY MULTIPLIER	1.00	.99	.97	.94	.91
SHR MULTIPLIER	1.00	.97	.93	.89	.85

(Courtesy of Trane Company)

TABLE C-7
CONDITIONED AIR FAN PERFORMANCE—CFM

NOMINAL COOLING CAP. Btu/hr / POWER FREQ. Hz	FREE DELIVERY	EXTERNAL STATIC PRESSURE* (INCHES OF WATER)				
		.25	.50	.75	1.0	1.5
600/60 % REDUCTION	240 —	220 8	190 20	150 38	105 56	
6000/400 % REDUCTION	260 —	235 10	210 19	175 33	135 48	
9000/60 % REDUCTION	315 —	300 5	275 13	250 21	220 30	
18000/60 % REDUCTION	330 —	315 5	295 11	270 18	240 27	
18000/400 % REDUCTION	655 —	625 5	580 11	530 19	470 28	335 49
9000/400 % REDUCTION	710 —	680 4	645 9	600 16	545 23	420 41
36000/60 % REDUCTION	1290 —	1215 6	1135 12	1060 18	980 24	765 41
36000/400 % REDUCTION	1375 —	1305 5	1230 11	1160 16	1090 21	900 35
60000/60 %REDUCTION	2010 —	1930 4	1850 8	1775 12	1685 16	1500 25
60000/400 % REDUCTION	2100 —	2040 3	1940 8	1860 11	1775 15	1590 24

*WET COOLING COIL RESISTANCE INCLUDED IN UNIT.

(Courtesy of Trane Company)

NOTE – The above tables were taken from Ref. 10. Model numbers and other data for compact units are given in Table 3-1.

external static pressure must be estimated and corrections applied to the air flow rate and cooling capacity. In the given example, for instance, if the pressure drop through the external air distribution system is 0.5 in. of water, Table C-7 shows that the rate of air delivery is reduced by 9%. Then, Table C-5 shows that this has the effect of reducing the cooling capacity by nearly 3%. The corrected cooling capacity would be about 18,250 Btu/hr (18,820 x 0.97), which is still adequate.

If the sensible heat ratio is substantially less than 1.0, Table C-4 should be used to select an environmental control unit of adequate capacity. In this case, cooling capacity and sensible heat ratio correction factors for lower than rated air flow rates are obtained from Table C-6.

Finally, it is well to caution against overdesign of a system by selection of air conditioners which are larger than necessary. Overcapacity may result in poor temperature control and inadequate dehumidification as a consequence of on-time being short compared to off-time. Furthermore, the larger units are more expensive, weigh more, and require more space and electrical power. This point is illustrated by the following example[2]:

	Nominal Unit Size, Btu/hr		
	40,000	60,000	% Increase
Weight, lb	445	600	30
Power Required, kW	9.8	15.5	63
Size, ft^3	17.4	26	49.5
Cost, Based on $0.10/(Btu/hr)	$4000	$6000	50

C-4 CALCULATION OF HEATING AND COOLING REQUIREMENTS FOR M292 VAN*

The heating and cooling requirements for the M292 Van can be determined by consideration of the various heat sources and sinks, and the modes of heat transfer between them. The first step is to define the internal and external design conditions accurately.

C-4.1 INTERIOR DESIGN AIR CONDITION

Different combinations of temperature, humidity, and air movement will produce the same relative feeling of warmth or cold in humans. Studies using prolonged exposures of test subjects to various psychrometric conditions showed median responses as indicated in Fig. C-2. This chart also shows the line of maximum tolerable conditions, as determined by Yaglou[5]. This chart enables one to pick an air condition, or condition line, which will yield a certain quality environment. The "comfortable" line on the ASHRAE Comfort Chart (Fig. C-2) is desirable for the M292 Van interior in all its uses. Since electronic equipment may abound in the enclosure, the humidity should not exceed 40%. This design point is indicated in Fig. C-2: 77°F dry bulb, 61°F wet bulb, 40% RH, enthalpy 27.4 Btu per lb of dry air.

C-4.2 EXTERIOR DESIGN AIR CONDITION

The exterior air condition which should be used as a design standard will also be a function of humidity as well as temperature. Not every combination of temperature and humidity is met throughout the world. MacDonald[6] has studied the probabilities of occurrence of various conditions throughout the world. His data are plotted in Fig. C-3. We have chosen to design to the 99.9% probability line. Just which point on this line will pose the maximum load on the air conditioner is not immediately apparent; this will depend on the relative importance of radiant and conductive heat transfer and the interchange of latent heat in the system. The only reliable way to determine the maximum load is to take a range of conditions and compute the maximum load. Table C-8 lists some choices along the 99.9% probability curve.

C-4.3 HEAT LOAD CALCULATION

Fig. C-4 gives a schematic representation of the various heat sources and sinks involved in

*This appendix is an edited version of Section VI of Ref. 7.

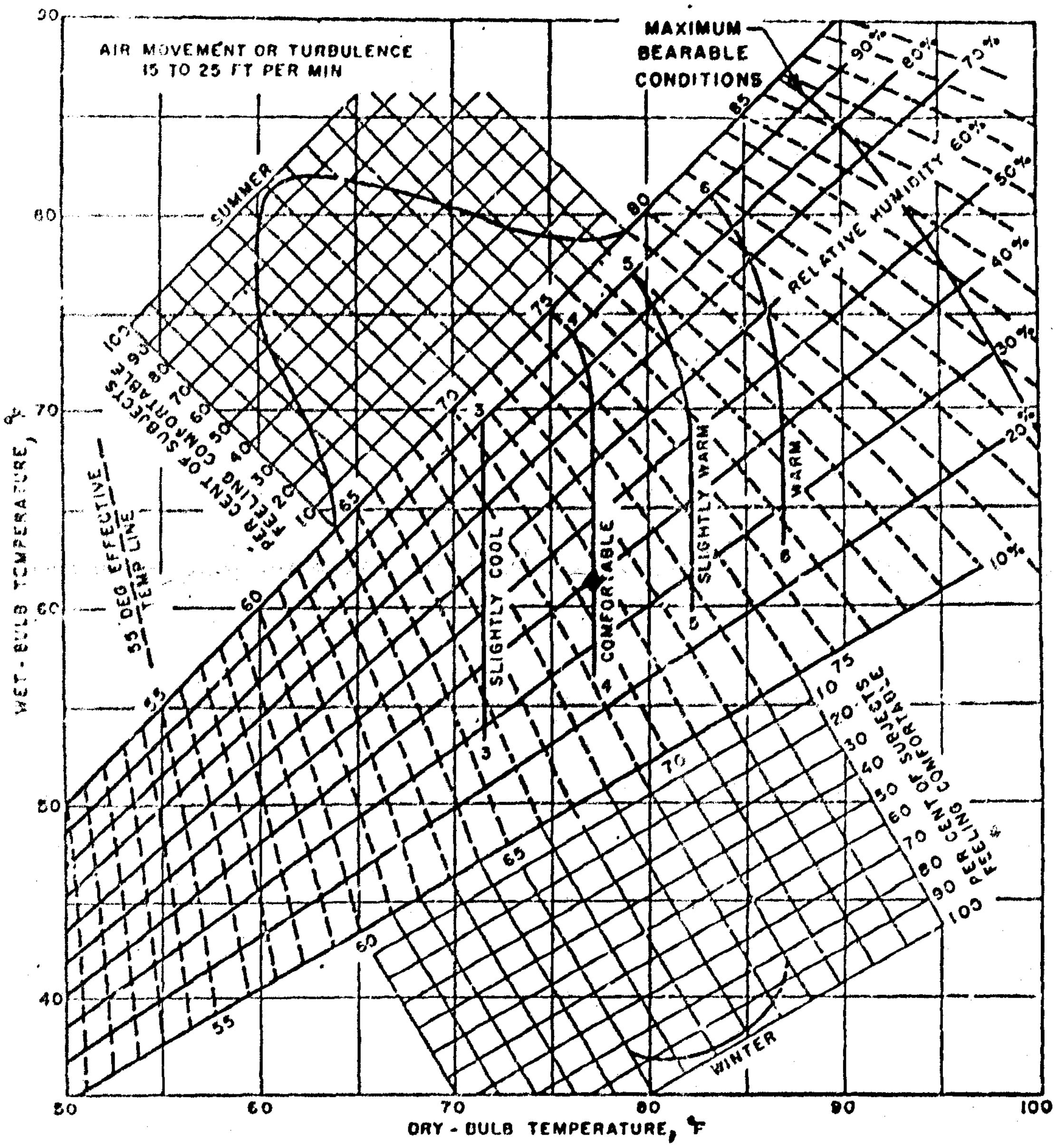


Figure C-2. Revised ASHRAE Comfort Chart. Copyrighted by ASHRAE. Reprinted by permission from ASHRAE Guide and Data Book 1967.

(The comfort distribution curves show that the maximum percentage of people should be comfortable at 71 ET in summer and at 68 ET in winter. These distribution curves are based on the response of persons immediately after entering a conditioned space. The solid lines (Nos. 3, 4, 5, and 6) show the response of subjects after approximately three hour occupancy. It appears from this chart that persons will feel quite warm when exposed to an environment at 85 ET, the maximum allowable in military applications.)

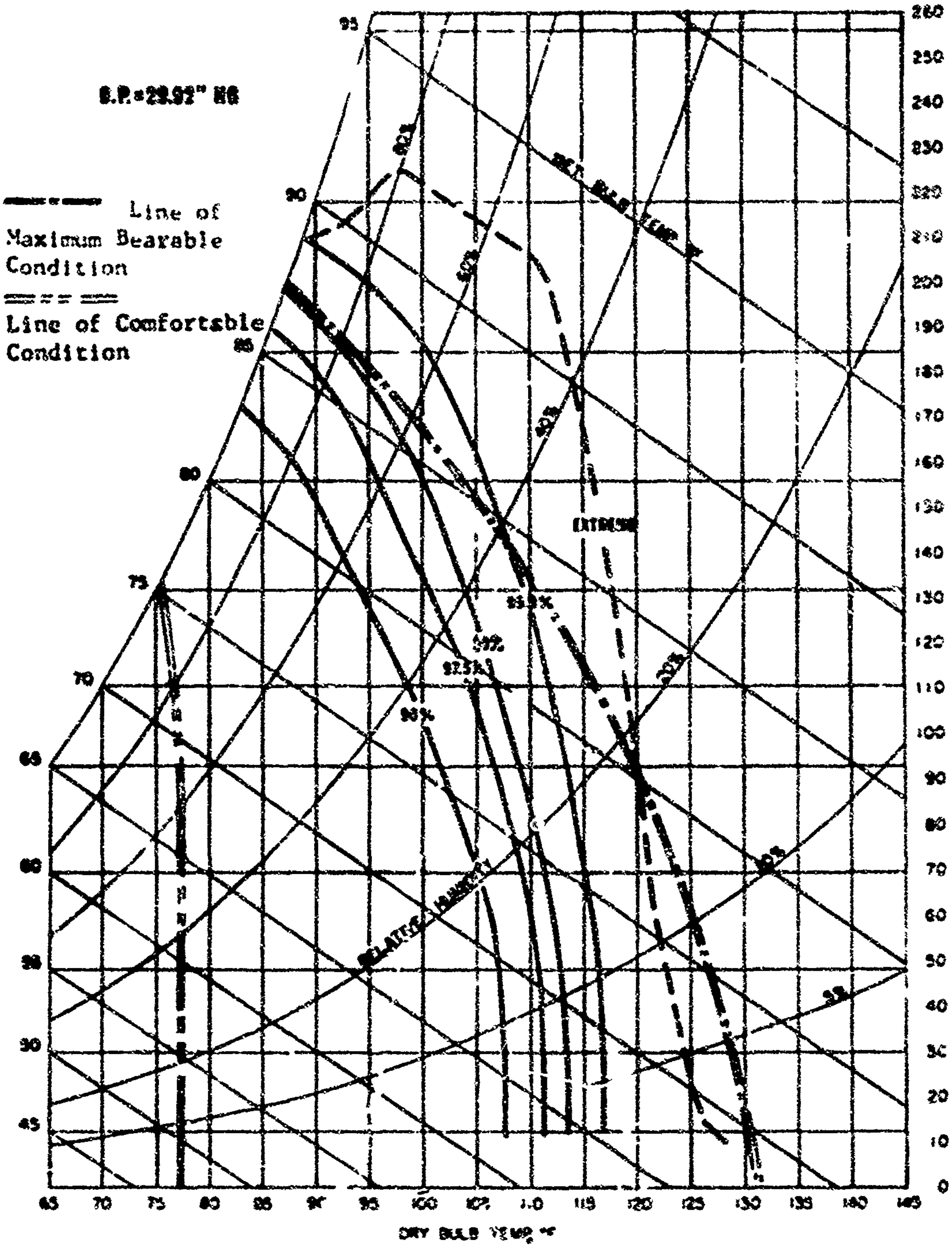


Figure C-3. Psychrometric Probability Chart[6]

TABLE C-8

PSYCHROMETRIC CONDITIONS AT 99.9% PROBABILITY

Condition	RH,† %	DBT,† °F	WBT,† °F	Enthalpy,* Btu/lb
A	0	117	83	28.1
B	10	117	72	35.6
C	20	114	78	41.2
D	40	107	85	48.6
E	60	101	88	53.0
F	100	89	89	54.6

*Read from Fig. A-1.

†Read from Fig. C-3.

the analysis. In this figure,

q_E = heat input from electrical equipment, Btu/hr

q_p = heat input from each van occupant (= 530 Btu/hr latent heat, + 220 Btu/hr sensible heat) (Ref. 4)

q_{sr} = total heat input through roof, Btu/hr

q_{sw} = total heat input through walls, Btu/hr

q_{ac} = heat removed by air conditioner, Btu/hr

h_i = enthalpy of air at design point in van interior, Btu/lb

h_a = enthalpy of air outside van, Btu/lb

Q_A = air flow through air lock, lb/hr

Q_L = air leakage, lb/hr

Q_a = $Q_A + Q_L$ = makeup air flow, lb/hr

t_i = interior temperature, °F

t_a = exterior air temperature, °F

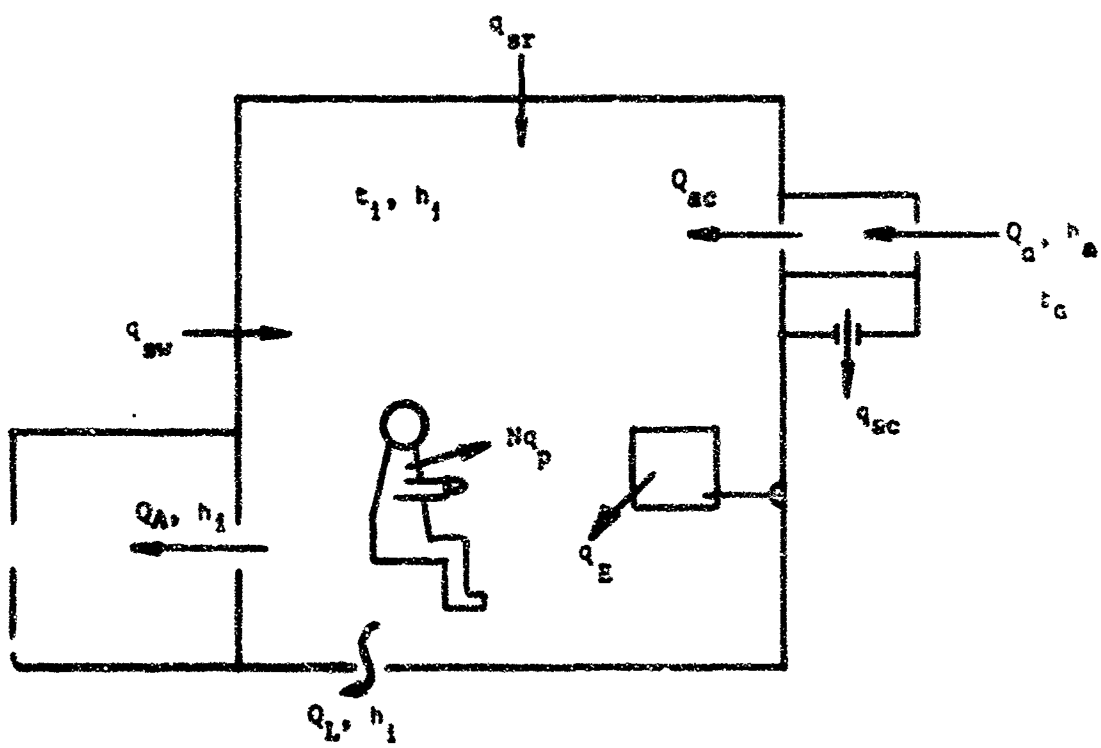


Figure C-4. Heat Sources, Sinks, and Surface Heat Transfer in M292 Van

N = number of occupants

Q_{ac} = conditioned air flow into van, lb/hr

1. *Heat Gains and Losses at Van Surfaces. Summer Condition*

The ASHRAE method for computing heat gains (or losses) through walls and roofs involves the use of an "Equivalent Temperature Differential" which sums all the effects of radiation and conduction (see Ref. 4.).

Then

$$\Sigma h_{ti} A_i = \Sigma \Delta t_i U_i A_i \qquad \text{(C-1)}$$

where

A_i = area of the *ith* element of the van surface, ft^2

h_{ti} = total heat transmission through the *ith* element resulting from both radiation and conduction, $Btu/(hr\text{-}ft^2)$

Δt_i = "equivalent temperature differential" for the *ith* element, °F

U_i = heat transfer coefficient for the *ith* element, $Btu/(hr\text{-}ft^2\text{-}°F)$

Taking the roof first, we assume the following:

a. The roof is equivalent to the "light construction" line of the ASHRAE table of equivalent temperature differentials.

b. We use the worst case for the roof as determining: 2 PM on a summer day.

c. We correct the differential upward to a continuous 95°F day, rather than an average summer day varying from 75° to 95°F as stated in the table; the correction is 10 deg for this. In addition, we add or subtract a temperature difference which corrects for the fact that our interior-exterior temperature differential is not always the 15°F on which the tables in the ASHRAE Guide are based. (The procedure for making these corrections is described in the Guide.)

With these conditions in mind, the Equivalent Temperature Differences can be read from the ASHRAE tables, and appropriate correlations applied. Corrections will be different for each of the chosen exterior design conditions. Furthermore, the Equivalent Temperature Differences will depend on the relative position of the sun and the van surfaces. We have assumed that the sun will be high in the sky to give maximum roof transfer; we orient the van with its side wall facing south. The remaining walls will be shaded. Table C-9 lists the Equivalent Temperature Differences for the chosen operating points for all four walls and the roof.

The next step is to determine the nature and area of the exposed surfaces. The configuration of the expanded van is shown in Fig. C-5. Fourteen separate surfaces make up its exterior.* However, we can group some of these and reduce calculation. These areas, together with the proper Equivalent Temperature Differences, are listed in Table C-10. The other entries in this table are explained in the paragraphs which follow.

The van walls are made of a three-layer composite, consisting of a metal exterior skin s, glass fiber insulation i, and tempered fiberboard interior panels p. The overall heat transfer coefficient U for the composite wall is:

$$U = \frac{1}{\frac{\ell_s}{k_s} + \frac{\ell_i}{k_i} + \frac{\ell_p}{k_p}} \qquad \text{(C-2)}$$

*The floor area was ignored in Ref. 7. Evidently, it was felt that the rate of heat transfer through the floor would be negligible by comparison with that through other surfaces. This is sometimes accomplished, for example, by walling in the space between the floor and ground levels, producing a dead air space underneath the van. Ordinarily, the rate of heat transfer through the floor is computed as it is for the walls and roof, except that it is not necessary to correct the temperature difference across the floor to take solar radiation into account.

TABLE C-9

CORRECTED EQUIVALENT TEMPERATURE DIFFERENCES

Temperatures, °F

Exterior Condition	Roof (Light)	N Wall (Dark)	S Wall (Dark)	E Wall (Dark)	W Wall (Dark)
A	97	45	65	47	55
B	97	45	65	47	55
C	94	42	62	44	52
D	87	35	55	37	45
E	81	29	49	31	39
F	60	17	37	19	27
	(Exposed)	(Shaded)	(Exposed)	(Shaded)	(Shaded)

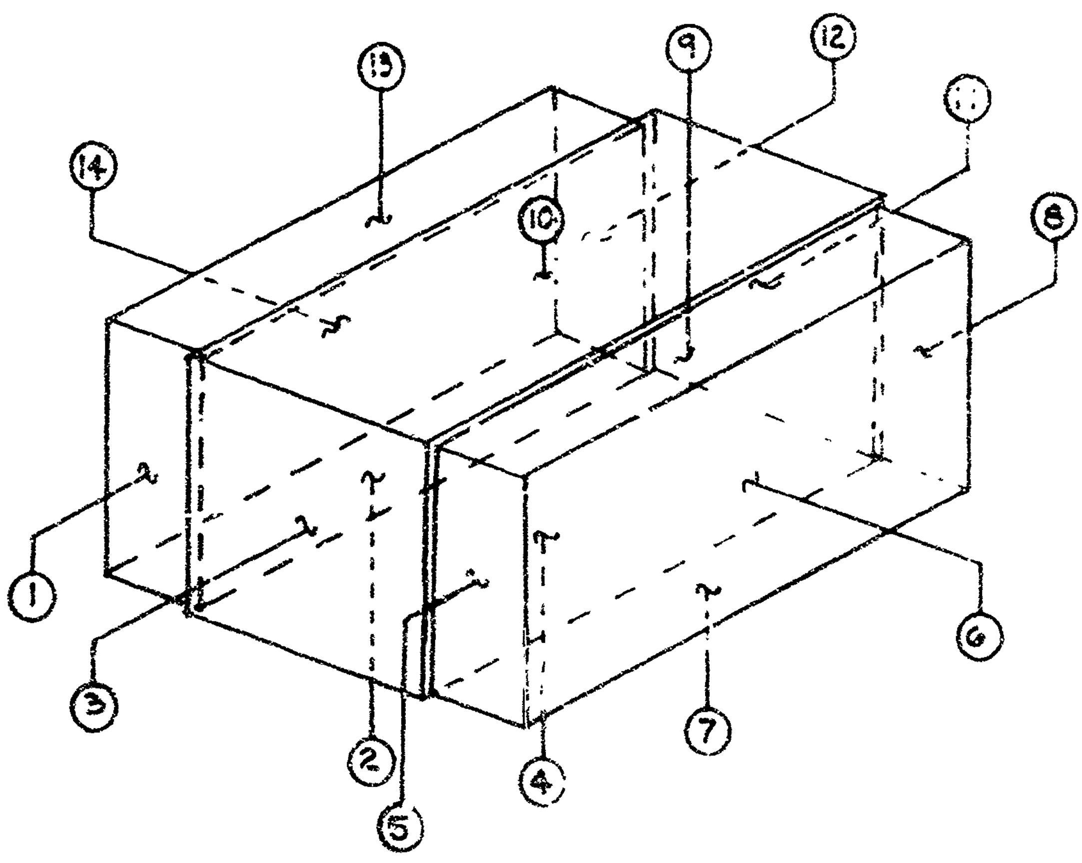


Figure C-5. Exterior Surfaces of M292 Van

TABLE C-10

TOTAL HEAT LOAD CALCULATIONS, SUMMER CONDITION: M292 VAN

Condition (Refer to Table C-9)		A		D		E		F	
Enthalpy h_a of entering air, Btu/lb		28.1		48.5		63.0		54.6	
Specific weight γ_a, lb/ft^3		0.0680		0.0685		0.070		0.072	
Elements	Area, ft^2	Δt, °F	q_w, Btu/hr	Δt, °F	q_w, Btu/hr	Δt, °F	q_w, Btu/hr	Δt, °F	q_w, Btu/hr
Roof (9, 10, 13)	251	97	6320	87	5677	81	5285	69	4502
S Wall (6)	122	65	2081	55	1746	49	1544	37	1174
E Wall (8, 11, 12)	147	47	1798	37	1414	31	1185	19	726
N Wall (14)	122	45	1427	35	1110	29	920	17	539
W Wall (1, 3, 5)	147	55	2102	45	1720	39	1491	27	1032
Sums	789		13715		11666		10435		7973
(U = 0.26 Btu/(hr·ft^2 °F) for all surfaces)									
Electrical Load, Btu/hr (est.)			9200		9200		9200		9200
Personnel (25 men, 750 Btu/hr each)			18750		18750		18750		18750
Air In (25 x 15 cfm) = 22,500 ft^3/hr = (22,500 γ_a) lb/hr			43625		75842		83475		88452
			85290		115458		121860		124375
Air Out 375 cfm, γ_i = 0.074 lb/ft^3 h_i = 27.2 Btu/lb*			45290		45290		45290		45290
Air Conditioner Load, Btu/hr			40000		70168		76570		79085
Air Conditioner Load, Tons**			3.34		5.85		6.39		6.60

*h_a = enthalpy of air outside van, Btu/lb
h_i = enthalpy of air flowing outward, Btu/lb
q_i = total heat lost by air flowing outward, Btu/hr
γ_i = specific weight of air flowing outward, lb/ft^3
**A standard ton of refrigeration corresponds to a heat absorption at a rate of 12,000 Btu/hr

Where layer thicknesses are

$\ell_s = 1/16$ in.

$\ell_i = 1$ in.

$\ell_p = 1/8$ in.

And layer heat transfer coefficients k are:

$k_s = 1.0$ Btu/(ft²-hr-°F/in.)

$k_i = 0.27$ Btu/(ft²-hr-°F/in.)

$k_p = 0.8$ Btu/(ft²-hr-°F/in.)

Substituting,

$$U = \frac{1}{\frac{1/16}{1} + \frac{1}{0.27} + \frac{1/8}{0.8}} = \frac{1}{3.9}$$

$$= 0.26 \text{ Btu/(hr-ft}^2\text{-°F)*}$$

2. *Other Heat Losses and Gains*

a. *Personnel.* We assume that van personnel are engaged in "Light Bench Work". Ref. 8 gives 750 Btu/hr total heat output per man in this situation**.

b. *Entering and Leaving Air Enthalpy.* We assume that 15 cfm of makeup air will be required per man. The heat supplied by this air will depend on the condition being analyzed; these values can be read from Table C-8. Air densities corresponding to these conditions are listed at the top of each condition column of Table C-10; these were obtained from the Psychrometric Density Chart, Fig. C-6. With these data in hand, the heat contribution q_a from the entering air can be calculated for each condition, using the expression

$$q_a = 60\, Q_a \gamma_a h_a \text{, Btu/hr} \qquad \text{(C-3)}$$

where

γ_a = the specific weight of the outside air, lb/ft³

q_a = total heat introduced by this air, Btu/hr

h_a = enthalpy of air outside van, Btu/lb

The heat removed by air leakage and air lock flow will be

$$q_l = 60\, Q_a \gamma_a h_l \text{, Btu/hr} \qquad \text{(C-4)}$$

where

q_l = total heat lost by air flow outward, Btu/hr

h_l = enthalpy of air flowing outward, Btu/lb

c. *Electrical Heat Input.* This is assumed to be 2700 W, or 9200 Btu/hr.

d. *Total Cooling Load**. The total cooling load is the algebraic sum of the previously listed items, i.e.,

Air conditioner load = (heat gain through surfaces)
+ (heat from occupants)
+ (heat from electrical equipment)
+ (heat from entering air)
− (heat in leaving air)

*Note that the thermal resistance of air films at inner and outer wall surfaces were ignored in this calculation. If taken into account as shown in par. A-2, Appendix A, the value of U would be 0.22 Btu/(hr-ft²-°F).

**See definition of q_a, par C-4.3, Appendix C, and footnote to item 2d which follows.

*Sensible and latent cooling loads were lumped together in Ref. 7 because the primary purpose of the calculations was to compare the total cooling loads under several conditions. Selection of an air conditioner would require that the two types of cooling load be separated, as discussed in par. C-3, Appendix C.

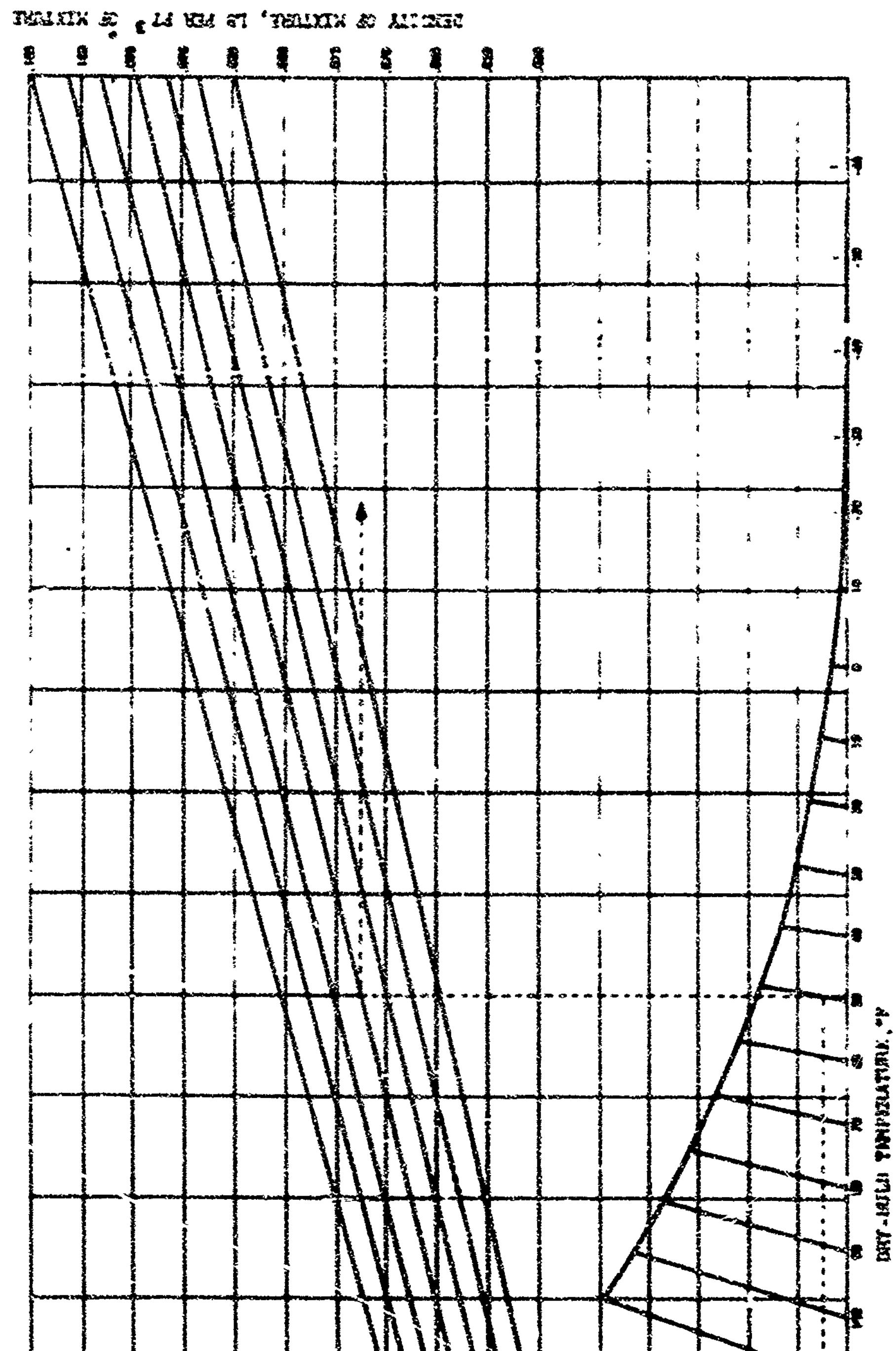


Figure C-6. Psychrometric Density Chart

These five terms and their sums are listed in Table C-10. The maximum load appears at the condition of saturation, *F*, and corresponds to 6.60 tons of refrigeration. The bulk of this load is in the incoming air; unless the ventilation rate can be reduced drastically, this cooling load cannot be reduced. This quantity of air is almost certain to be required for several reasons. Smoking is one of these; dissipation of odors and flammable vapors in medical air stations, and rest and relief uses is another; metabolic (oxygen-carbon dioxide) requirement is another; the need for reasonable air conditioner discharge temperatures is still another. (Ventilation requirements are discussed further in par. 1-4 of this handbook.)

3. *Heat Gains and Losses: Winter Condition*

The minimum design temperature for the van interior is 60°F. Again assuming 40% relative humidity, we have a design interior enthalpy of 19.2 Btu/lb of dry air. The exterior condition is −65°F; humidity is of no significance here. The heating load is computed in a manner similar to that for the cooling load described in sub pars. 1 and 2 of par. C-4.3.

(Heating Load) = (heat loss through surfaces)
− (heat from occupants)
− (heat from electrical equipment)
+ (heat gain of entering air)

The first of these terms is much simpler than in the summer case; the worst condition is at night, when no solar heat is available and losses are purely conductive:

$$q_c = UA_T\Delta t, \text{ Btu/hr} \qquad \text{(C-5)}$$

where

q_c = total conductive loss, Btu/hr

U = heat transfer coefficient for the walls, 0.26 Btu/(hr-ft²-°F)

A_T = total area of the expanded van = 1040 ft²

Δt = wall temperature differential

$= [60-(-65)] = 125°\text{F}.$

Substituting these values, we have q_c = 33,800 Btu/hr.

For the heat supplied by occupants, we cannot assume that the van will be fully loaded; the worst case is a single occupant, supplying 750 Btu/hr. The worst case for electrical power is perhaps 200 W or, 683 Btu/hr. The heat to be supplied to entering air must be based on a reasonable flow rate. Since there is no provision for lowering the flow to accommodate a single occupant, this flow would be 375 cfm, raised from −65° to 60°F at 40% relative humidity. Taking the enthalpy difference, [19.2 − (−15.6)] or 34.8 Btu/lb, and a density of 0.1 lb/ft³, we have heat gain q_a of entering air

$$q_a = 375 \times 60 \times 0.1 \times 34.8 \text{ Btu/hr}$$

$$= 78{,}200 \text{ Btu/hr}$$

Summing terms, we get for the heat to be supplied

$$33{,}800 - 750 - 683 + 78{,}200 = 110{,}567 \text{ Btu/hr}$$

C-5 ALIGNMENT CHART FOR CALCULATING COOLING LOADS

Fig. C-7 enables one to make a quick estimate of the cooling load of a mobile structure. Larger, more usable copies of the chart and a booklet explaining the methods used in developing the nomograph are available from the Ellis and Watts Company, Cincinnati, Ohio.

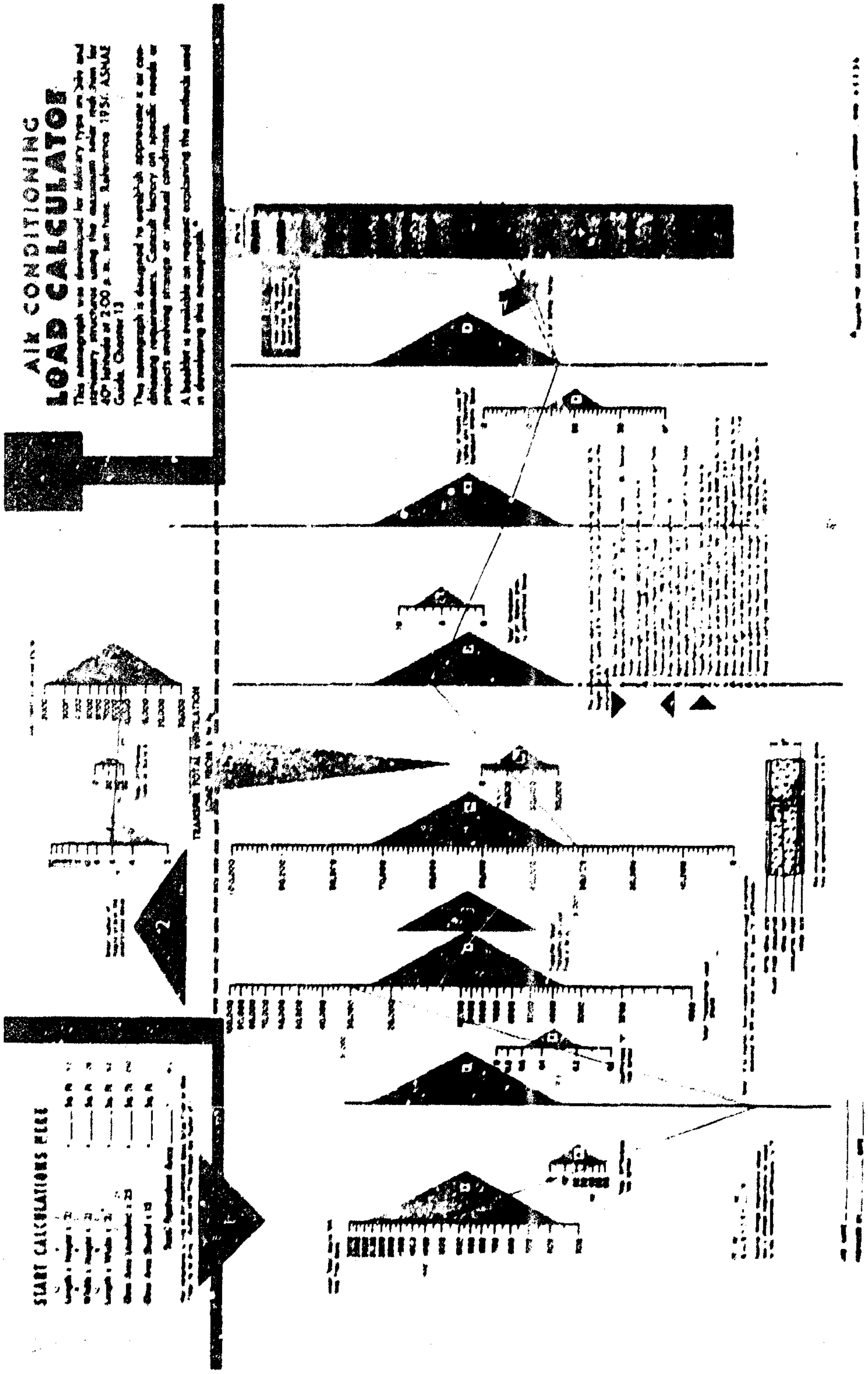


Figure C-7. Air Conditioning Load Calculator Nomograph

REFERENCES

1. W.A. Ramsey, "Effects of Altitude on Equipment Performance", Air Conditioning, Heating and Ventilating 65, 41-48 (1968).

2. Trane Engineering Bulletin, *Military Air Conditioner Selection and Application*, Section 5-10, pp. 67-86, The Trane Co., La Crosse, Wisconsin, 25 June 1968.

3. Trane Co., *Trane Air Conditioning Manual*, 39th printing, The Trane Company, La Crosse, Wisconsin, July 1967.

4. ASHRAE, *Handbook of Fundamentals*, Amer. Soc. of Heating, Refrigerating ,and Air-Conditioning Engineers, Inc., New York, N.Y., 1967.

5. C.P. Yaglou, *Tolerance Limits of People for Cold, Heat and Humidity in Underground Shelters*, Proceedings of the Meeting on Environmental Engineering in Protective Shelters, pp. 31-40, February 8, 9, and 10, 1960.

6. John L. MacDonald, *A Review of High Temperature Extremes in AR 705-15, MIL-STD-210A as Compared with World-Wide Weather Data*, Mechanical Dept., USAERDL (now USAMERDC), Fort Belvoir, Va., May 1964.

7. R.D. Rivers, K.L. Westlin, and R.J. Boylan, *Collective Protection for Command Post Vehicles, M292 Design Study Report*, Amer. Air Filter, Co., Inc., Louisville, Kentucky, 4 May 1965 (AD-462 507).

8. *ASHRAE Guide and Data Book*, Chapter 26: "Air Conditioning and Cooling Load", Amer. Soc. of Heating, Refrigerating and Air-Conditioning Engineers, Inc., New York, N.Y., 1963.

9. R.E. Franseen, *Cooling and Heating Load Calculations for Environmental Control Equipment Applications*, U.S. Army Engineer Research and Development Laboratories (now USAMERDC), Fort Belvoir, Virginia, 10 September 1965.

10. Trane Catalog DS-259, *Lightweight Military Air Conditioners*, The Trane Co., LaCrosse, Wisconsin, May 1965.

APPENDIX D

AIR CONDITIONER TOPICS

D-1 TECHNICAL CHARACTERISTICS FOR AIR CONDITIONING, VAN TYPE (Copied from Ref. 1, pp. 69-70, with minor changes in Item 1.a.)

"1. The air conditioners shall be designed to provide the environment within the van, hut, shelter, or enclosure that is necessary to insure proper operation of the installed electronic or other sensitive equipment, and shall

a. Range in capacity from 6,000 to 180,000 Btu/hr.

b. Maintain temperature, humidity, and fresh air circulation necessary for proper functioning of the primary equipment installed in the enclosure.

c. Be equipped with dust filtering devices.

d. When required, be compatible with chemical, biological, and radiological (CBR) filtering devices.

e. Be capable of being mounted on or in the associated van by organizational maintenance personnel without requiring extensive modifications of the van or interfering with the efficient operation of the primary equipment.

f. Be sufficiently rugged to withstand prolonged cross-country hauling in a mounted position and be capable of operation continuously for 6 months without a major overhaul.

g. Operate at a noise level such that it will not interfere with the efficient operation of the equipment in the van or shelter. Appropriate components will be treated for the elimination of interference with radio communications in accordance with applicable Signal Corps specifications.

h. Be air transportable as a part of the item of equipment in which it is to be used, and in the same phase of airborne operations.

i. Be capable of operation, as specified, at one or more of the following voltages and frequencies: 120, 208, 416 VAC and 60 or 400 cycle.

j. Be capable, where required, of being driven by either a gasoline engine or an electric motor.

k. Have mechanical and electrical parts adequately protected to prevent injury to personnel.

l. Be as light in weight and small in bulk as is compatible with other requirements.

m. Be constructed of readily available noncritical materials as far as practicable.

n. Be capable of being manufactured in quantity by modern fabrication methods.

o. Be designed with maximum simplicity commensurate with their intended performance. Ease of operation and maintenance to be considered in each feature of design.

p. Where applicable, the design of the unit shall be such that its operation will not interfere with local radar scanning devices.

q. Be treated to resist fungus and moisture, as specified.

r. Where required, be capable of interior and exterior mounting and be designed for a maximum number of applications.

s. Have the inherent capability of acceptable performance under Basic Operation Conditions and Extreme Hot Weather Operating Conditions as established in paragraphs 7a and 7c of AR 705-15, Change 1[2(†)], except that operation will not be required at ambient temperatures of +60°F and lower, and shall be capable of safe storage and transportation under the conditions as established in par. 7d of AR 705-15, Change 1[2(†)]. Where electric heaters are specified and are in integral component, be capable of providing the rated heating output of the unit at a minimum temperature of -50°F*.

t. Where necessary, be treated for the elimination of interference with radio communications in accordance with applicable Signal Corps specifications."

D-2 REFRIGERANT CIRCUIT WITH HOT-GAS BYPASS

The refrigerant circuit described, quoted from Chapter 5 of Ref. 3, is typical of circuits using a hot gas bypass for temperature control. Refer to Fig. D-1.

"Cool, low-pressure refrigerant gas enters the refrigerant compressor through the suction service valve. The compressor increases the pressure of the refrigerant gas which is discharged into the condenser coil through the discharge service valve. The temperature of the refrigerant gas is increased by the heat of compression.

"As the warm refrigerant gas flows through the condenser coil, it is rapidly cooled by air drawn through the coil by the condenser fans. As the refrigerant gas is cooled, it condenses and is stored in the refrigerant receiver.

"Liquid refrigerant flows from the receiver through the drier and sightglass to the evaporator solenoid valve. The drier removes foreign particles, sludge, and moisture from the refrigerant. The sightglass provides an indication of the quantity of refrigerant in the system and the . . . [presence] of moisture in the refrigerant.

"When electrical power is applied, the evaporator solenoid valve opens, allowing liquid refrigerant to flow through the motor-operated valve to the evaporator expansion valves. The motor-operated valve responds to inputs from an electronic temperature sensing circuit, opening and closing the refrigerant lines, [and thus] modulating refrigerant flow in series with the evaporator expansion valves to maintain evaporator discharge temperature at 73° ± 3°F.

"Temperature-sensitive expansion valve sensor bulbs are strapped to the outlet lines of the evaporator coil. As the temperature at the sensor bulbs increases, the expansion valves open, allowing refrigerant to enter the evaporator coil.

"Pressure inside the evaporator coil is kept relatively low by the suction of the refrigerant compressor. As liquid refrigerant enters the evaporator from the expansion valves, it is vaporized by the low internal evaporator pressure. The heat necessary for vaporization is extracted from air drawn through the evaporator coil by the evaporator fan.

"The cooled air leaving the evaporator coil is supplied to the area or equipment requiring air conditioning. As air is cooled by the evaporator coil, moisture in the air is condensed and drained off through drain hoses.

"Cool refrigerant gas leaving the evaporator coil returns to the suction side of the compressor and the cycle is repeated.

"During periods of operation with relatively small heat loads on the air conditioner, insufficient heat for refrigerant vaporization is drawn from the evaporator airflow. Under

*The minimum temperature was given as -65°F in Ref. 1.
†AR 705-15 has been superseded by AR 70-38, *Research, Development, Test, and Evaluation of Materiel for Extreme Climatic Conditions*, 5 May 1969.

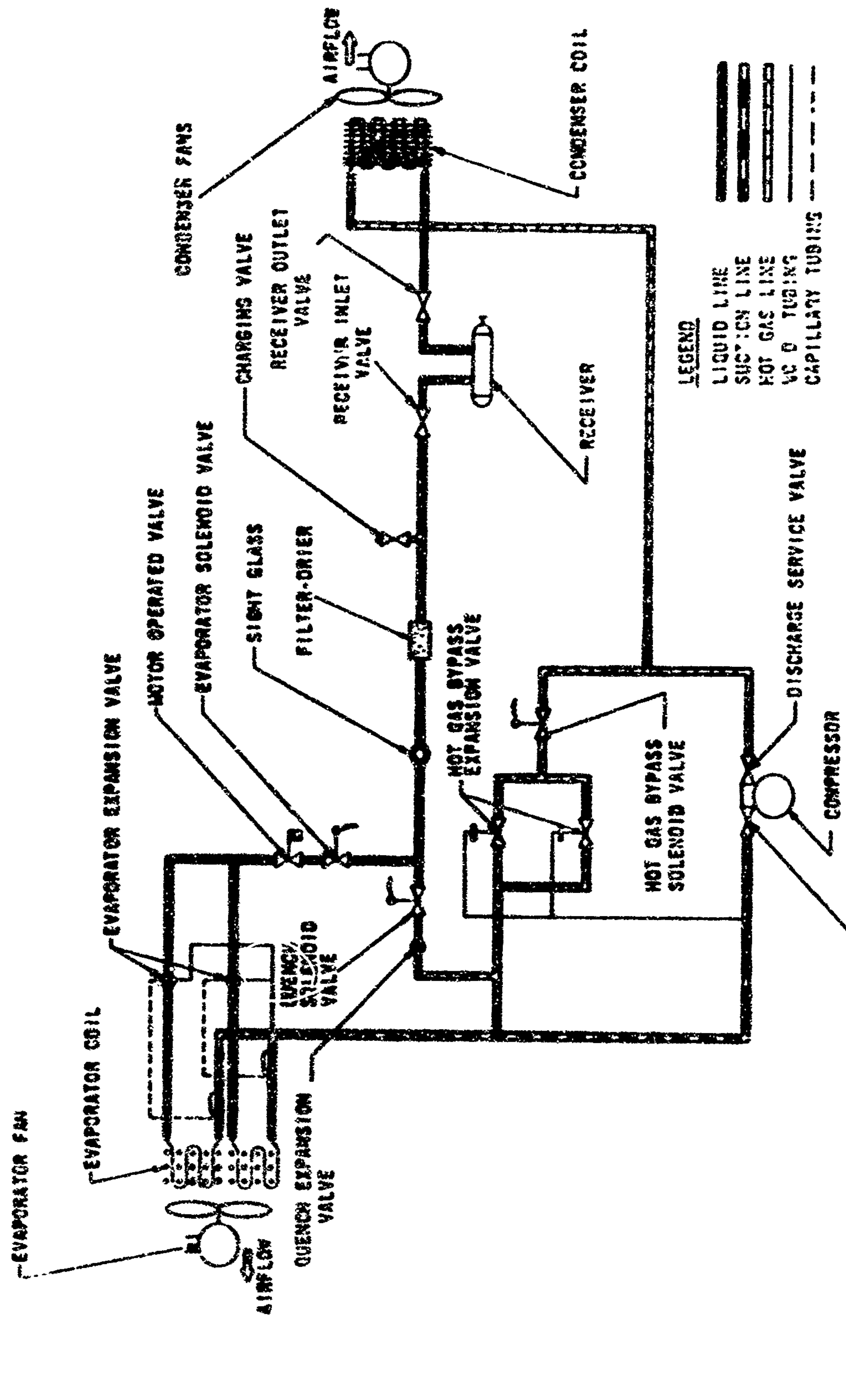


Figure D-1. Refrigerant Flow Diagram[3]

this condition, the refrigerant suction pressure starts to drop below tolerance.

"When suction pressure decreases, pressure sensing tubing connected to two hot gas bypass valves opens the bypass valves. Warm, high pressure refrigerant gas from the compressor discharge flows directly into the suction line, keeping suction pressure above lower limits.

"One function of the cool refrigerant entering the suction side of the compressor is to provide cooling for the compressor motor. During hot gas bypass operation, the temperature of the suction gas increases, resulting in increased compressor internal temperatures. The sensor bulb of the quenching expansion valve relays the suction temperature increases to the quenching expansion valve. Liquid refrigerant is evaporated into the suction line, reducing suction temperature to within tolerance during bypass operation."

REFERENCES

1. R.B. Sherfy, *Nominal 36,000 Btu/hr, Conventional, Standard Weight, Single-Section, 208-volt, 3-Phase, 60-cycle (Model CE36HBC6-208) Air-Conditioning Unit*, Report 1854, U.S. Army Engineer Research and Development Laboratories (now USAMERDC), Fort Belvoir, Va., May 1966 (AD-485 823L).

2. AR 705-15, *Operation of Materiel Under Extreme Conditions of Environment*, 4 October 1962, including Change 1, 14 October 1963. (Superseded by AR 70-38, *Research Development, Test, and Evaluation of Materiel for Extreme Climatic Conditions*, 5 May 1969.)

3. TM 5-4120-295-15, *Air Conditioner, Floor Mounting, Air-Cooled 60,000 Btu/hr, 208/416 volts 50/60 cycle, 3-Phase, Carrier Air Conditioning Co. Model 76E34104*, Headquarters, Dept. of the Army, Washington, D.C., 7 November 1966.

APPENDIX E

COLLECTIVE PROTECTION SYSTEM (CPS) FOR COMMAND POST VEHICLE*

A drawing of the recommended CPS for the M292 Expandable Van is shown in Fig. E-1.

The system provides mobile protection for equipment inside the van, plus up to four persons also riding inside. To accomplish this, liner (9)† is installed permanently in the van body, and a gas particulate filter unit is installed between the liner and the shell of the van at (3). Connection to the outside is made through pipe (4); discharge from the filter unit is directly to the interior of the van liner. Fold bars (10) are provided at each corner to allow the liner to folw inward with the van side panels.

Liner (9) is attached to air lock (15) by zippers (14). A staircase or ramp (19) is installed inside this air lock. In most cases, extension (21) will be zippered onto air lock (15) at (20). This extension allows a swing door (24) to be used at the outer end of the air lock, as well as at the inner end (13).

For Medical Aid Station use, and perhaps for Rest and Relief, where large numbers of troops would be processed through the van, the anteroom (25) would be attached by zipper (26). This tent-like structure is supported by external frame (27) (shown only in part). Door (30) is a flap door to allow rapid entry with litter cases. Entry (29) is necessary to allow flap door (30) to hang vertically and seal properly.

Cables (16) attached to the van and to the door frame around door (24) support air lock (15) when the system is not pressurized. Straps (17) are provided to suspend a litter inside the air lock for the decontamination period. Lamps (18) and (28) are provided to illuminate the air lock and ante-room respectively. Telephone jacks at the control station inside the van (6), inside the air lock (22), and both inside and outside the ante-room (31) allow communication between the chambers.

Control of air flow is provided by control panel (5) connecting to valves (12) and (23) through cables (8). Power is also fed through cable (7) to externally located filter unit (1). These units can provide the flow of approximately 400 cfm required for use of the van with up to 22 persons inside. Air from this unit is supplied to the distribution duct in the roof of the van (11) via a flexible duct (2). An anti-backdraft valve (32) is incorporated to prevent ingress of contaminants into the ante-room; since this valve is mechanical, no connection to the control system is required.

REFERENCE

1. R. D. Rivers, K. L. Westlin, and R. J. Boylan, *Collective Protection for Command Post Vehicles, M292 Design Study Report*, Amer. Air Filter Co., Inc., Louisville, Kentucky, 4 May 1965 (AD-462 507).

*With minor editorial changes, this Appendix was taken from Chapter XI of Ref. 1.

†These numbers refer to the components identified in Fig. E-1.

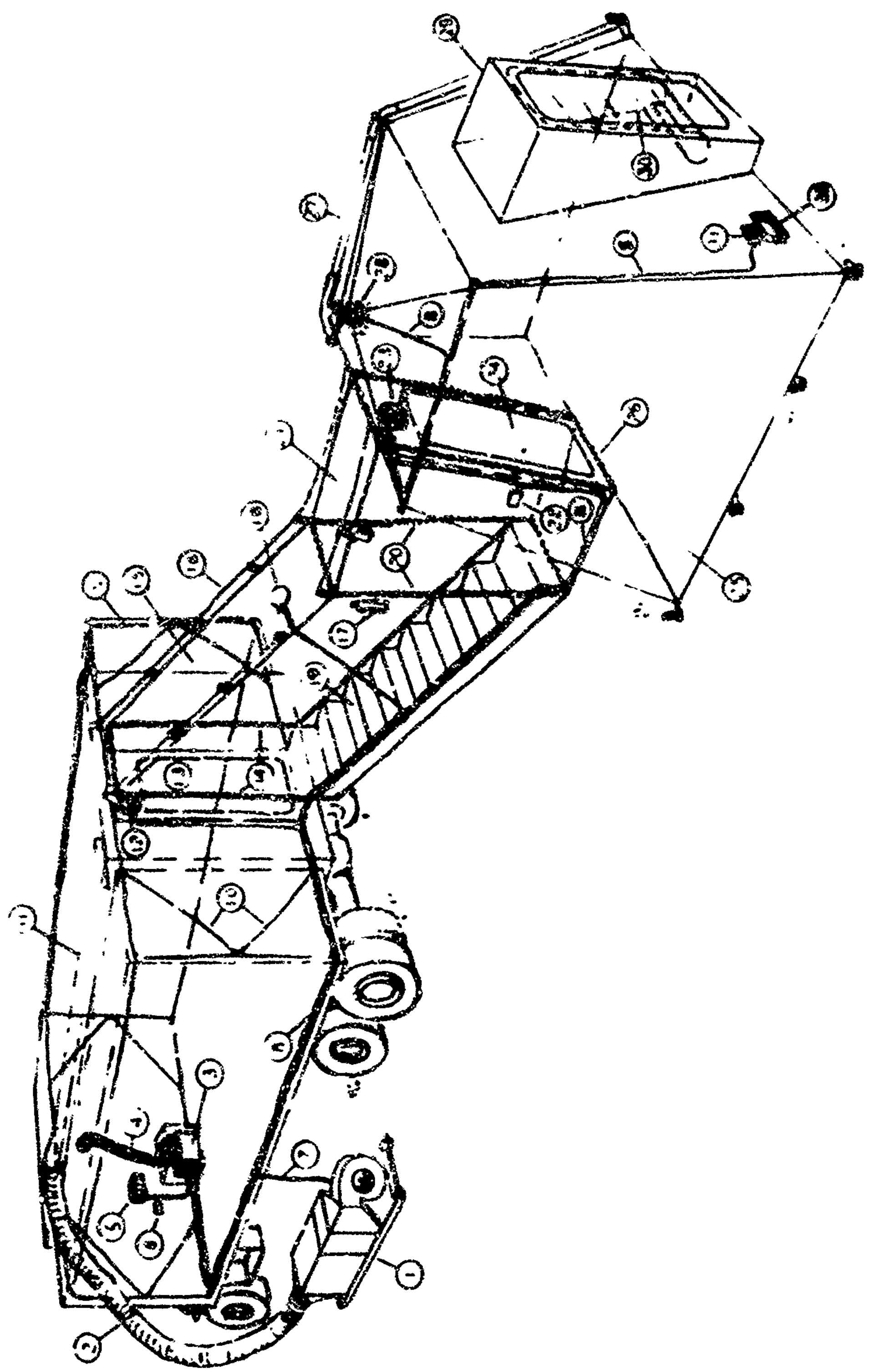


Figure E-1. Recommended Collective Protection System for M292 Expandable Van¹

GLOSSARY*

Absorption. A process whereby a material extracts one or more substances present in an atmosphere or mixture of gases or liquids, accompanied by physical change, chemical change, or both, of the material.

Activated Alumina. A form of aluminum oxide which adsorbs moisture readily and is used as a drying agent.

Activated Carbon. A form of carbon made porous by special treatment by which it is capable of adsorbing various odors, anesthetics, and other vapors.

Adsorption. The action, associated with surface adherence, of a material in extracting one or more substances present in an atmosphere or mixture of gases and liquids, unaccompanied by physical or chemical change. Commercial adsorbent materials have enormous internal surfaces.

Air, Ambient. Generally speaking, the air surrounding an object.

Air Circulation. Natural or imparted motion of air.

Air Conditioner. An assembly of equipment for the control of at least the first three items enumerated in the definition of *air conditioning.*

Air Conditioning. The process of treating air so as to control simultaneously its temperature, humidity, cleanliness, and distribution to meet the requirements of the conditioned space.

Air Cooling. Reduction in air temperature due to the abstraction of heat as a result of contact with a medium held at a temperature lower than that of the air. Cooling may be accompanied by moisture addition (evaporation), by moisture extraction (dehumidification), or by no change whatever of moisture content.

Air, Outdoor. Air taken from outdoors and, therefore, not previously circulated through the system.

Air, Saturated. Moist air in which the partial pressure of the water vapor is equal to the vapor pressure of water at the existing temperature. This occurs when dry air and saturated water vapor coexist at the same dry-bulb temperature.

British Thermal Unit (Btu). The Btu is defined as 778.177 foot-pounds. Approximately, it is the heat required to raise the temperature of a pound of water from 59° to 60°F.

Calorie. Heat required to raise the temperature of 1 gram of water 1°C, actually from 4° to 5°C. Mean calorie = 1/100 part of the heat required to raise 1 gram of water from 0° to 100°C.

Collective Protection. The protection of an area and/or one or more personnel from toxic agents used in Chemical-Biological warfare without use of individual protection equipment.

Condenser. A vessel or arrangement of pipe or tubing in which a vapor is liquefied by removal of heat.

Decibel. A unit used to express the relation between two amounts of power. By definition the difference in decibels between two powers P_1 and P_2, P_2 being the larger, is dB difference $= 10 \log_{10}(P_2/P_1)$. Used in acoustics.

Dew Point. See *Temperature, Dew-Point*

*Wherever possible, the definitions have been taken from the chapter on Terminology in *ASHRAE Handbook of Fundamentals* (1967).

Emissivity. The capacity of a material to emit radiant energy. Emittance is the ratio of the total radiant flux emitted by a body to that emitted by an ideal blackbody at the same temperature.

Enthalpy. Thermodynamic property of a substance defined as the sum of its internal energy plus the quantity *Pv/J*, where *P* = pressure of the substance, *v* = its volume, and *J* = the mechanical equivalent of heat. Formerly called by the obsolescent names *total heat* and *heat content*.

Evaporator. That part of a refrigerating system in which refrigerant is vaporized to produce refrigeration.

Exfiltration. Air flow outward through a wall, leak, membrane, etc.

Failure Rate. The number of failures of an item per unit measure of life (cycles, time, miles, events, etc., as applicable for the item).

Heat, Latent. Change of enthalpy during a change of state. With pure substances, latent heat is absorbed or rejected at constant pressure.

Heat, Sensible. Heat which is associated with a change in temperature; specific heat exchange of temperature; in contrast to a heat interchange in which a change of state (latent heat) occurs.

Heat Pump. A refrigerating system employed to transfer heat into a space or substance. The condenser provides the heat while the evaporator is arranged to pick up heat from air, water, etc. By shifting the flow of air or other fluid a heat pump system may also be used to cool the space.

Hertz. One hertz (Hz) equals 1 cps (adopted by the Eleventh General Conference on Weights and Measures in Paris, October, 1960).

Horsepower. Unit of power in foot-pound-second system, work done at the rate of 550 ft-lb per sec, or 33,000 ft-lb per min.

Humidify. To add water vapor to the atmosphere; to add water vapor or moisture to any material.

Humidity Ratio. Weight of water vapor (steam) associated with one lb weight of dry air.

Humidity, Relative. The ratio of the mol fraction of water vapor present in the air, to the mol fraction of water vapor present in saturated air at the same temperature and barometric pressure, approximately, it equals the ratio of the partial pressure or density of the water vapor in the air, to the saturation pressure or density, respectively, of water vapor at the same temperature.

Inch of Water. A unit of pressure equal to the pressure exerted by a column of liquid water 1 in. high at a temperature of 4°C or 39.2°F.

Infiltration. Air flowing inward as through a wall, crack, etc.

Load, Estimated Design. In a heating or cooling system, the sum of the useful heat transfer, plus heat transfer from or to the connected piping and ductwork, plus heat transfer occurring in any auxiliary apparatus connected to the system.

Maintainability. A characteristic of design and installation which is expressed as the probability that an item will be retained in or restored to a specified condition within a given period of time, when the maintenance is performed in accordance with prescribed procedures and resources.

Mean-Maintenance-Time. The total preventive and corrective maintenance time divided by the total number of preventive and corrective maintenance actions during a specified period of time.

Mean-Time-Between-Failures (MTBF). For a particular interval, the total functioning life of a population of an item divided by the

total number of failures within the population during the measurement interval. The definition holds for time, cycles, miles, events, or other measure of life units.

Mean-Time-To-Repair (MTTR). The total corrective maintenance time divided by the total number of malfunctions during a given period of time.

Mechanical Equivalent of Heat. An energy conversion ration of 778.177 ft-lb = 1 Btu.

Microbar, Dyne per Square Centimeter. A unit of pressure commonly used in acoustics. One microbar is equal to 1 dyne per square centimeter.

Micron. A unit of length, the thousandth part of 1 mm or the millionth of a meter.

Mission Time. The period of time in which an item must perform a specified mission.

Mobile Unit. A facility which can be moved from one locale to another with very little time and effort. In many cases the unit is mounted directly on a motor vehicle, and can be readied for transport in a few hours.

Module An assembly, forming part of a larger assemblage, which is designed for complete replacement as a unit. Hence, the terms modular unit, modular construction, modular maintenance, modular design, etc.

Radiation, Thermal (Heat). The transmission of energy by means of electromagnetic waves of very long wavelength e.g., solar radiation. Radiant energy of any wavelength may, when absorbed, become thermal energy and result in an increase in the temperature of the absorbing body.

Refrigerant. The working fluid in a refrigeration cycle, absorbing heat from a reservoir at low temperature and rejecting heat at a higher temperature.

Refrigerating System, Absorption. A refrigerating system in which the refrigerant gas evolved in the evaporator is taken up in an absorber and released in a generator upon the application of heat.

Reliability. The probability of a device performing its purpose adequately for the period of time intended under the operating conditions encountered. For a system with independent components, the overall reliability is based on the product of the individual reliabilities; e.g., three independent components with a 90% reliability each will have an overall reliability of 0.9 x 0.9 x 0.9 or 72.9%. Similarly, 100 components with a 99% reliability each will have an overall reliability of only 36.5%.

Sound Pressure Level. The sound pressure level, in decibels, of a sound is 20 times the logarithm to the base 10 of the ratio of the pressure of this sound to the reference pressure. The reference pressure shall be explicitly stated.

Speech Interference Level (SIL) The speech interference level of a noise is the average, in decibels, of the sound pressure levels of the noise in the three octave bands of frequency 600-1200, 1200-2400, and 2400-4800 cps.

Temperature, Dew-Point. The temperature at which the condensation of water vapor in a space begins for a given state of humidity and pressure as the temperature of the vapor is reduced. The temperature corresponding to saturation (100 percent relative humidity) for a given absolute humidity at constant pressure.

Temperature, Dry-Bulb The temperature of a gas or mixture of gases indicated by an accurate thermometer after correction for radiation.

Temperature, Effective An arbitrary index which combines into a single value the effect of temperature, humidity, and air movement on the sensation of warmth or cold felt by the human body. The numerical value is that of

the temperature of still, saturated air which would induce an identical sensation.

Temperature, Wet-Bulb. Thermodynamic wet-bulb temperature is the temperature at which liquid or solid water, by evaporating into air, can bring the air to saturation adiabatically at the same temperature. Wet-bulb temperature (without qualification) is the temperature indicted by a wet-bulb psychrometer constructed and used according to specifications.

Throw. The horizontal or vertical axial distance an air stream travels after leaving an air outlet before the maximum stream velocity is reduced to a specified terminal level, e.g., 200, 150, 100, or 50 fpm.

Time, Down (Downtime). That element of time during which the item is not in condition to perform its intended function.

Ton of Refrigeration. A useful refrigerating effect equal to 12,000 Btu per hr; 200 Btu per min.

Transmittance, Thermal (U Factor). The time rate of heat flow per unit area under steady conditions from the fluid on the warm side of a barrier to the fluid on the cold side, per unit temperature difference between the two fluids.

Transportable Unit. A facility generally designed to be brought to a given location and remain for months at a time. Considerably more time and effort are needed to prepare a transportable unit than to prepare a mobile unit for shipment to a new locality. For example, a unit supplied with retractable wheel assemblies (for local positioning), but which needs a flat bed truck for transporting to new areas over several miles away, is considered transportable.

U Factor. See: Transmittance, Thermal.

Ventilation. The process of supplying or removing air, by natural or mechanical means, to or from any space. Such air may or may not have been conditioned.

Volume, Specific. The volume of a substance per unit mass; the reciprocal of density.

ABBREVIATIONS

AMC	Army Materiel Command
CB	Chemical-Biological
CBR	Chemical-Biological-Radiological
CP	Collective Protection
CPE	Collective Protection Equipment
DA	Department of the Army
ECU	Environmental Control Unit
GED	Gasoline-Engine-Driven
GPFU	Gas-Particulate Filter Unit
HEL	Human Engineering Laboratories
MTBF	Mean-Time-Between-Failures
MTBM	Mean-Time-Between-Maintenance
MTTR	Mean-Time-To-Repair
QMDO	Qualitative Materiel Development Objectives
QMR	Qualitative Materiel Requirements
SDR	Small Development Requirements
SPL	Sound Pressure Level

FOR THE COMMANDER:

CHARLES T. HORNER, JR.
Major General, USA
Chief of Staff

OFFICIAL:

[illegible]. J. PHILLIPS
Colonel, GS
Chief, HQ Admin Mgt Ofc

DISTRIBUTION:
Special

☆ U. S. GOVERNMENT PRINTING OFFICE: [illegible]

ENGINEERING DESIGN HANDBOOKS

*Development Guide for Reliability, Part Three, Reliability Prediction

*Development Guide for Reliability, Part Four, Reliability Measurement

*Development Guide for Reliability, Part Five, Contracting for Reliability

*Development Guide for Reliability, Part Six, Mathematical Appendix and Glossary

Carriages and Mounts Series

Cradles

Top Carriages

Bottom Carriages

Equilibrators

Elevating Mechanisms

Traversing Mechanisms

Wheeled Amphibians

The Automotive Assembly

Automotive Suspensions

Automotive Bodies and Hulls

SUPPLEMENTARY

INFORMATION

AD-889588

DEPARTMENT OF THE ARMY
HEADQUARTERS UNITED STATES ARMY MATERIEL COMMAND
5001 Eisenhower Ave, Alexandria, VA 22333

AMC PAMPHLET
No. 706-120
CHANGE 1

19 June 1974

Engineering Design Handbooks

CRITERIA FOR ENVIRONMENTAL CONTROL OF MOBILE SYSTEMS

AMCP 706-120, Engineering Design Handbook, Criteria for Environmental Control of Mobile Systems, 16 September 1971, is changed as follows:

a. Paragraph 4-5(1), page 4-4, is changed to read:

(1) Mission reliability* of 95 percent with a mission time of 24 hr with a 90 percent confidence

b. Paragraph 4-5(2), page 4-4, is changed to read:

A mean-time-between-failures* of 480 hr with 90 percent confidence

(AMCRD-TV)

FOR THE COMMANDER:

OFFICIAL:

J. R. Groundwater

JOHN LYCAS
Colonel, GS
Chief, HQ Admin Mgt Ofc

JOSEPH W. PEZDIRTZ
Major General, USA
Chief of Staff

DISTRIBUTION:
Special